Wood Extractives: Main Families, Functional Properties, Fields of Application and Interest of Wood Waste

Jean Louis Lepetit N'Guessan
Bobelé Florence Niamké
N'guessan Jean Claude Yao
Nadine Amusant

Abstract

The extractives contained in wood are compounds with a very high added value in various fields (e.g., pharmaceuticals, cosmetics, agri-food). These extractives can be classified into four groups: lipid components (terpenes and terpenoids), waxes and fats, phenolic compounds, and alkaloids. This review is particularly focused on the description of the main families of extractives contained in wood waste, with their properties and the potential applications made to date. It also makes a brief report on some conventional techniques for extracting wood extractives, with an eye toward recovering wood waste in our country. These extractives, particularly phenolic compounds, fall into several categories: simple phenols, lignans, flavonoids and tannins. They have chemical and biological properties such as antioxidants, antiradicals, anti-termites, antifungals, anticancer, inhibitors of type 1 human immunodeficiency virus, antimutagenics, and antimicrobial properties. They are also used in food preservation as well as wood protection. This review sums up the interest that should be focused on the availability in large quantities of wood waste in our environment, which, far from being a problem, could be the solution to certain current and future problems.

Wood, an important source of raw materials, is an essential material in the world because of its various possible uses in industry, construction, agriculture, and other fields. Indeed, wood is an important source of income in some countries such as Côte d'Ivoire. However, given the growing demand for wood due to its importance, we have an increase in logging and a large amount of wood waste produced by processing companies in our country. It is estimated that only 30 percent of each felled tree is recycled, whereas 70 percent of the tree ends as the waste produced (Saha 2015). Most wood waste and byproducts are subject to material recovery (e.g., paper pulp, particle board, insulation) or energy recovery as biofuels to produce heat or electricity (Meullemiestre 2014). Yet in the tree, apart from the main constituents of the cell wall (cellulose, hemicellulose, and lignin) that form the largest part of the wood (Roesyadi 1987, Alén et al. 1995), several families of chemical compounds (primary and secondary metabolites) are also present (Niamké et al. 2011). Low molecular weight compounds (as opposed to wood macromolecules) are better known as extractives because they can be easily extracted by the choice of suitable solvents (e.g., organic, aqueous; Stevanovic and Perrin 2009, Meullemiestre 2014, Bruneton 2016) and are found in the porous structure of the wood. Extractives include a whole range of compounds, most of which are secondary metabolites (i.e., compounds that are not essential for plant growth). There is minimal difference in the chemical structure of different species of trees (or shrubs) at the level of the three main constituents of wood—

The authors are, respectively, PhD student (lepetitgrandpere34@gmail.com / louis.nguessan21@inphb.ci [corresponding author]), Assistant Professor (bobele.niamke@inphb.ci), and Researcher (yaojc3@yahoo.fr), Félix Houphouët-Boigny National Polytech. Inst. of Yamoussoukro (INP-HB), Côte d'Ivoire; and Researcher (Nadine.Amusant@EcoFog.gf), French Agric. Research Centre for International Development (CIRAD), ED Dept., UMR Ecofog, BP 701, 91310 Kourou Cedex, French Guiana. This paper was received for publication in March 2023. Article no. 23-00015.

Forest Prod. J. 73(3):194–208.
doi:10.13073/FPJ-D-23-00015

cellulose, lignin, and hemicelluloses—as opposed to the great variation in composition of extractives from one species to another (Hon and Shiraishi 2001). Indeed, the content of extractives, which can range from 5 to 20 percent, as well as their nature vary according to the species, geographical site, genetics, or season. The study by Hon and Shiraishi (2000) confirms that tropical woods have more extractive content than do woods from temperate regions. Also, literature (Nzokou et al. 2005, Mburu et al. 2007, Mounguengui et al. 2016, Saha et al. 2018) indicates that many tropical woods contain high levels of extractives. This particularly reinforces the interest shown in them with a view to their valuation. Indeed, extractives present in wood are responsible for its color (Amusant 2003, Gierlinger et al. 2004), its smell, its hygroscopy (Krutul 1992), its natural durability (Barbosa et al. 2007, Niamké et al. 2011), its physical and mechanical properties such as dimensional stability (Royer et al. 2010), and its acoustic properties (Minato and Sakai 1997). Many extractives exhibit particular biological activities; wood extracts have been used for centuries as sources of traditional remedies (Arnason et al. 1981). Known for their properties and derived from renewable resources, extractives are already the subject of much research and development in various fields (pharmaceutical, agri-food, cosmetics; Mounguengui 2008, Huang et al. 2009). Wood extractives are little or not at all exploited in Côte d'Ivoire. However, they inhibit the growth of wood alteration agents (bacteria, termites, and fungi; Niamké et al. 2012, Maranhão et al. 2013) and have biocidal properties (Haluk and Jodin 1994, Haluk and Roussel 2000). Extractives confer sustainability by infusing the wood of less durable species with extracts from the wood of more resistant species; they constitute active substances that can be used in the formulation of wood preservation products (Brocco et al. 2017, Rodrigues et al. 2012). The possible uses of wood extractives and the availability of large quantities of wood waste in our environment, mainly in Côte d'Ivoire, offer prospects for better recovery of this wood waste. Our work therefore presents advances related to the fields of application of wood extractives (mainly tropical woods) as well as the potential recovery of their waste (abundant in the industrial environment) in the agricultural area. After a brief presentation of extractives and the main families of extractives, we review fields of application of wood extractives, particularly in agriculture, with regard to their functional properties.

Wood Extractives

Wood, like wood waste, is mainly made up of three natural polymers (cellulose, hemicellulose, and lignin), which comprise the cell wall and form most of the wood (Roesyadi 1987, Alén et al. 1995). Several families of secondary metabolites are also present in the tree, in the wood itself, but also in the leaves, roots, bark, and nodes. Extractives organic substances represent about 2 to 5 percent of the composition of softwoods, 3 to 8 percent of temperate hardwoods, and up to 18 to 22 percent of tropical woods (Mosedale et al. 1998). These molecules specific to each forest species, despite their low concentration in the wood compared with that of the three structural polymers, are responsible for the variability of several properties within the various species but also within the same tree (Schultz et al. 1995, Mosedale et al. 1998, Schultz and Nicholos 2000, Lacandula 2002, Amusant et al. 2007). These metabolites, essential to the adaptation and survival of the tree, fulfill the role of defense by constituting a chemical or physical barrier against wood degradation agents. The presence of extractives in the heartwood strongly influences the natural durability, olfactory, physico-mechanical, or even acoustic properties of the wood (Stevanovic and Perrin 2009). Hawley et al. (1924) first highlighted the link between natural sustainability and extractives; then many researchers, such as Taylor et al. (2006) and Santana et al. (2010), have shown that the natural durability of a wood is linked to the nature of the extractives compounds it contains. Extractives, synthesized during duraminization, contribute to the robust biological resistance of wood against xylophagous organisms without the need to resort to preservation treatments or protection methods. The in vitro studies performed by Oliveira et al. (2010) and Kirker et al. (2013) showed that, once extracted, the wooden blocks were more easily degraded by lignivorous organisms (fungi and termites). Extractives contribute a lot to the protection of wood against lignivorous organisms. Different families, genera, and species of wood contain different types of extractives. Some of these molecules are true 'chemotaxa'; i.e., they are markers whose presence is characteristic of the family, genus, or species. These chemotaxons make it possible to identify the plant material ('chemical signature'). For example, the *Cupressaceae* family is the only source of terpene compounds of an aromatic nature, the tropolones, including the thuyaplicins found in cedar heartwood (Stevanovic and Perrin 2009). The diversity of structures of these molecules allows them to be classified into several families (Stevanovic and Perrin 2009): terpenoids (including tropolones), waxes and fats, polyphenols (benzene compounds containing several phenolic hydroxyls), salts of organic acids, complex carbohydrates, and nitrogen compounds (proteins, alkaloids). Extracts from different woods and barks are always complex mixtures and their composition depends on the extraction method used (Royer 2008, Diouf et al. 2009).

Extraction methods

Extractives are particularly localized in the lumen (Gandini and Belgacem 2002) and cell wall or in specialized cells such as the resin canals in conifers, as well as in the interstitial spaces, and can be easily extracted by the choice of suitable solvents (e.g., organic, aqueous; Stevanovic and Perrin 2009, Meullemiestre 2014, Bruneton 2016). We present a brief description of the classical methods of extraction (solid or liquid) for the sake of understanding.

Soxhlet extraction.—This extraction technique was named after Baron Von Soxhlet, who created this procedure in the mid-19th century (Mitra 2003). This method is based on reflux and siphoning to constantly extract the sample from the plant with fresh solvent, thus combining the processes of percolation and reflux using heat (Patra et al. 2018). The Soxhlet is one of the most used techniques for extraction. Some of the advantages of Soxhlet extraction are the preservation of the sample in contact with the fresh solvent, maintenance of a relatively high extraction temperature resulting from the heat of the distillation flask, absence of the need for filtration after leaching, simplicity of operation, and low cost. The main disadvantages of Soxhlet extraction are the long extraction time, use of a large amount of solvent, the impossibility of using agitation to speed up the process, and the possibility of thermal decomposition of sensitive compounds when exposed to heat (Wang and Weller 2006).

Infusion.—This is an extraction technique widely used in traditional medicine (Patra et al. 2018). The infusion is prepared by adding a small amount of plant material to the solvent at high temperature, which allows extraction in a short time (Gamboa-Gómez et al. 2017). To facilitate the extraction of compounds, plant material should be cut into small pieces (Rakotoniaina et al. 2018). This method produces extracts abundant in essential oil (Malca-Garcia et al. 2019). However, it has the disadvantage of using a large amount of solvent (Tiwari 2015). Also, the use of a high temperature can cause the degradation of thermolabile compounds (Malca-Garcia et al. 2019).

Maceration.—This technique is considered a simple extraction process. It consists of immersing the wood sample for a long period in a solvent to extract the soluble components (Patra et al. 2018). The greatest advantage of this method is its simplicity and the fact that it does not risk degrading thermolabile compounds, but it does not allow the bioactive compounds to be completely extracted from the plant.

Steam distillation and hydrodistillation.—In those processes that are suitable for distillation of heat-sensitive compounds, the applied heat is the primary cause of disruption of the cellular structure of the plant material, allowing the heat-sensitive compounds to be released. The heating temperature plays an important role because it must be sufficient to release the desired compounds (Tongnuanchan and Benjakul 2014). In steam distillation, water is boiled in one compartment and the resulting vapor passes through plant matter in another compartment. Alternatively, direct steam can be introduced into the sample for extraction. In hydrodistillation, however, water and plant material are placed in the same vessel and boiled together (Selvamuthukumaran and Shi 2017). Besides the similarity of these two extraction methods, steam distillation allows a higher yield of essential oils and a better collection of volatile compounds. The small number of volatile compounds recovered during hydrodistillation is due to the hydrolysis reaction caused by the combined action of water and high temperature, which can lead to degradation of certain compounds. On the other hand, distillation at steam can avoid this degradation and allow production of higher quality essential oils because the plant material is not in direct contact with water (Ali et al. 2019).

Large families of extractives

Wood, like its waste that we find abandoned in the environment, is made up of extractives compounds including waxes, fats, terpenes and terpenoids, fatty acids, monosaccharides, alkaloids, and phenolic compounds. Extractives can be extracted from waste and then used for other purposes, and for this they can be classified into four categories. The first category includes terpenes and terpenoids, and some of these extracts are also called gems. The second category includes aliphatic compounds such as saturated and unsaturated fatty acids, alkanes, and fatty alcohols (e.g., triglyceride, palmitic acid, stearic acid). A third category concerns phenolic compounds. This large class includes simple phenols (vanilin), lignans (pinoresinol, hinokiresinol), flavonoids, tannins, and stilbenes (Hillis 1975, Fengel and Wegner 1989, Jodin 1994, Saha 2015). The fourth category comprises the alkaloids.

Terpenes and terpenoids

Terpenes.—Terpenes are synthesized by the epithelial cells (specialized tissue of the parenchyma), which line the resin canals. Terpenes have a basic formula of multiples of isoprene units $(C5H8)n$ (Fig. 1). They can be classified according to the number of isoprene units:

- $n = 2$: monoterpenes. These are the most common. They have the formula C10H16 and include many isomers (e.g., pinenes, germacrene, cadinene).
- $n = 3$: sesquiterpenes, C15H24 (β-Cadinene).
- $n = 4$: diterpenes, C20H32 (e.g., pimaradiene, larixol, manoyloxide).
- $n = 5$: sesterpenes (C25H40).
- $n = 6$: triterpenes (C30H48) (e.g., betulinic acid, oleanols).
- $n = 8$: polyterpenes (C40H64) (gutta-percha).

Terpene compounds have several roles in the tree, such as resistance to diseases and attacks by microorganisms, and creation of odor (nerolidol, farnesol, cedrol). Terpenes protect plants and wood against pathogens such as molds, fungi, and bacteria and can attract pollinating insects or repel herbivores. Thus, following an attack by a parasite or predators, the concentrations of these compounds increase. Tropolones are compounds responsible for the natural durability of certain woods. Saniewska and Jarecka (2008) have shown that hinokitiols (β-thujaplicin) are able to strongly inhibit the growth of fungi such as *Coriolus versicolor, Phanerochaete chrysosporium, Poria placenta,* and *Gloephyllum trabeum* (Saniewska and Jarecka 2008, Nuutinen 2018). Sterols are compounds of the cell membrane that participate in its stabilization. Phytol is a diterpene that is part of the structure of chlorophyll.

Terpenoids.—Terpenoids are molecules that contain oxygenated groups (Fig. 2). They are classified into mono, di, oligo, and polyterpenes (Bugrein and Bujassoum 2016); these are the compounds of terpene derivatives, and have forms such as alcohol (-OH), acid (-COOH), ketone (=O).

Terpenoids are anticancer compounds. Their mechanisms of action are varied and include processes such as neutralization of oxidative stress, potentiation of endogenous antioxidants, enhancement of detoxification potential, and others. Betulinic acid is a pentacyclic triterpenoid used as a folk remedy by Native Americans. It is a molecule that is adsorbed by intestinal cell membranes (Sharma et al. 2017). Monoterpenes (Camphene, (R)-camphor, (R)-carvone, 1,8-cineole, cuminaldehyde, (S)-fenchone, geraniol, (R)-linalool, (1R, 2S, 5R)-menthol, myrcene, and thymol) have antifungal activities against certain phytopathogenic fungi such as *Rhizoctonia solani* and *Fusarium oxysporum*, the latter causing green and black mold (Marei et al. 2012). For example, Garcia et al. (2008) demonstrated that L-carvone from *Pinus sylvestris* strongly inhibits fungal growth. Turley et al. (2006) demonstrated that these compounds are more powerful in destroying *Escherichia coli*. Betulins are triterpene pentacyclics present in birch (*Betula* spp.) bark, they have specific qualities (antimold and antibacterial). Lupeol is a triterpene with chemopreventative, cytotoxic, and antioxidant effects.

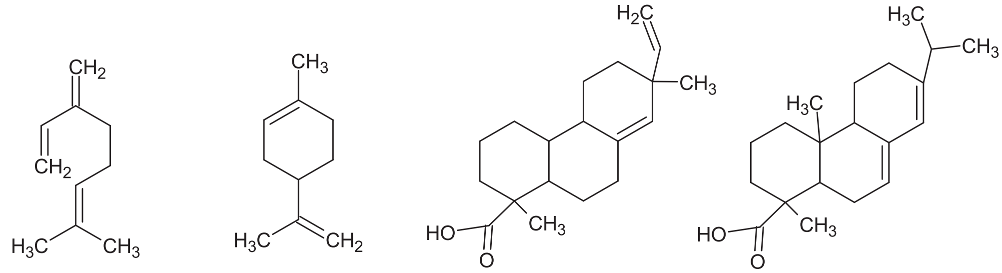


Figure 1.—The structures of some main known terpenes.

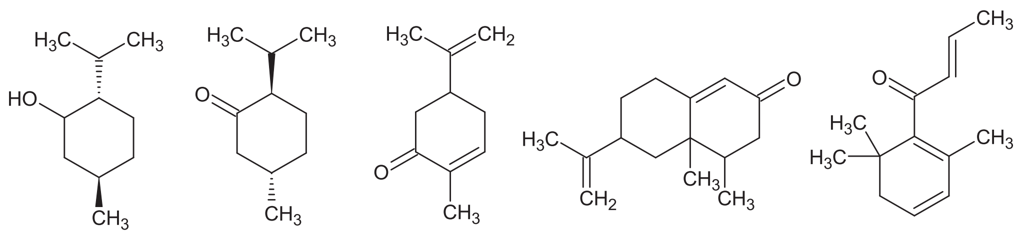


Figure 2.—The structures of some main known terpenoids.

Saturated and unsaturated fatty acids

Fatty acids, molecules that are scarce in free form in fresh fats, are hydrophobic aliphatic chain carboxylic acids, saturated or unsaturated depending on whether they contain or do not contain double bonds. They can contain 2 to 24 or more carbon atoms (Rustan and Drevon 2005). The general chemical formula of saturated fatty acids is: CH3 -(CH2) n - COOH. Unsaturated fatty acids can contain between one and six double bonds and are said to be monounsaturated or polyunsaturated, depending on the case. African ecosystems are full of many multipurpose plant species that remain wild and underexploited. In the tropics, there are many sources of vegetable oils available but not exploited or not used optimally (Dahouenon-Ahoussi et al. 2012). In the case of *Griffonia simplicifolia*, this plant belongs to the *Fabaceae* family (Kumar et al. 2010, EspItalier 2014, Mehta et al. 2015) and is native to the forests of the coasts of Central and West Africa, in particular Gabon, Liberia, Côte d'Ivoire, Ghana, and Togo (Brendler et al. 2010). It is a plant very well known to the populations thanks to its richness in curative virtues. Its seeds contain biochemical compounds, in this case fat, which can also be used in food or for other purposes. Oils are used in the preparation of various dishes or other products useful to humans (e.g., soap, cosmetics). Most often, they contain essential fatty acids for the harmonious functioning of the body (Aboubakar Dandjouma et al. 2008). Vegetable oils are sought after for their quantities and their qualities as compared with animal fats, which are saturated with saturated fatty acids. In the case of softwoods, these are esterified fatty acids derived from di- and triglycerides, or steroid esters, representing 0.15 to 0.19 percent of the dry mass in spruce (*Picea* spp.) knots (Willför et al. 2003). In softwoods, there are several fatty acids such as linoleic acid and stearic acid. There are mono, di, or triglycerides in wood extractives. Fats and waxes can influence the pulping process and the wettability of wood (Coelho et al. 2007).

Phenolic compounds

The phenolic compounds of wood are very varied (Haslam 1998, Macheix et al. 2005). They are characterized by at least one aromatic ring with one or more linked hydroxyl groups, but above all by their biosynthetic origin. The most common biosynthetic pathway is the shikimic acid pathway. It allows the synthesis of metabolites from sugars which leads to aromatic amino acids and then, by deamination, to cinnamic acids and their many derivatives. A second pathway involves acetate, which leads to polyacetates, which often form polycyclic compounds (Stevanovic and Perrin 2009, Bruneton 2016). Derivatives carrying several hydroxyl functions are called polyphenols; they include simple phenols (Fig. 3), phenolic acids, and coumarins, as well as polymerized forms. Plant phenolic compounds have in recent years inspired gradually increasing interest on account of their supposed beneficial effects on health and the possibility of exploiting them as food ingredients (Karonen et al. 2004). They reduce the oxidative deterioration of lipids and thus enhance the capacity and nutritional value of foods (Kähkönen et al. 1999). Phenolic compounds are among the most studied compounds among secondary metabolites, but many of them have properties that are still poorly understood (Raven et al. 2000). There are $>$8,000 molecules identified and isolated to date, which are mainly synthesized in the plant kingdom. According to their basic skeleton, several families of natural phenolic compounds can be distinguished; e.g., simple phenols, flavonoids, quinones, stilbenes, lignans, tannins.

Functional properties.—These phenolic compounds play a preventive role against cancer and heart problems. They also have a protective effect against ultraviolet rays, pathogens, herbivores, and lipids protect against oxidation

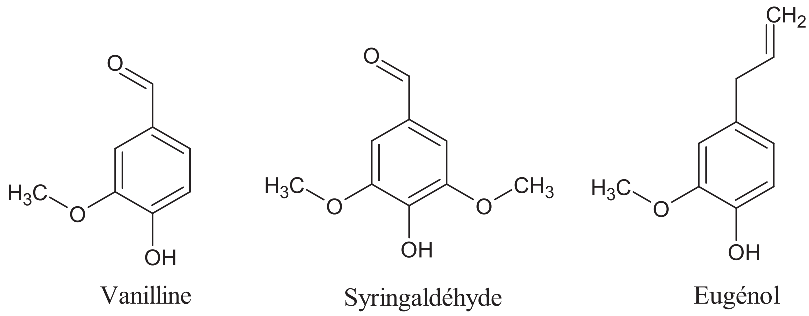


Figure 3.—Some examples of simple phenols.

of the cell membrane (Sghaier et al. 2011, Da Silva et al. 2016). Some of these polyphenolic compounds have antioxidant and antimicrobial activities, thus increasing interest in extraction of these compounds (Fernandez-Agullo et al. 2015). Other studies have shown that polyphenols have antibacterial, anticarcinogenic, and osteoinductive properties (Lišková et al. 2015). Salicylated derivatives, e.g., have anti-inflammatory, analgesic, and antipyretic properties. Among these derivatives, the best-known phenolic acid is salicylic acid (isolated from willow bark), which has been used to synthesize acetylsalicylic acid. The latter is marketed as 'aspirin' (Bruneton 2016).

Flavonoids.—Flavonoids are the most numerous among phenolic compounds (Raven et al. 2000). The structure of flavonoids comprises 15 carbons (C6-C3-C6), with 2 aromatic rings (C6) connected by a heterocyclic pyran ring of the 3-carbon bridge (C3; Nogales-Bueno et al. 2017); the variation as well as the hydroxylation profile of the chroman ring (C rings) are factors in the diversity of flavonoids such as anthocyanins, flavan-3-ols, flavones, flavanones, and flavonols (Fig. 4). Some flavonoids or the B ring are connected at the C3 and C4 position, such as isoflavones and neoflavonoids. Another class of flavonoid families is the Chalcones; the latter do not have the heterocycliqye C ring. These structural variations are the origin of the physicochemical properties, the biological properties attributed to these compounds (Ohmura et al. 2000, Macheix et al. 2005, Hooper and Cassidy 2006). These compounds act by different mechanisms of capture of free radicals and by chelation of metal ions.

The antioxidant capacities of many flavonoids are much stronger than those of vitamins C and E. Indeed, Flavonoids are able to scavenge free radicals directly through a hydrogen atom, the radicals are rendered inactive, where (R●) is a free radical, and (Fl-O●) represents a flavonoid phenoxy radical. The free radical (Fl-O●) formed can react with a second radical to give a stable quinone (Pietta 2000). This antioxidant activity is known as ''reactive oxygen species scavenging.'' *Eucalyptus*, buckwheat (*Eriogonum* spp.), and sophora (*Sophora* spp.) are plants rich in flavonoid glycoside; they are used for the treatment of venous and capillary disorders. Pterocarpanes are flavonoids with good antifeedant activity. This is the case for naringenin, which is renowned for its antiviral, antitumor, anti-inflammatory, anti-allergic, antibacterial, anticarcinogenic, and vascular-protective activities (Arima et al. 2002). However, the antioxidant activity depends on the arrangement of the functional groups on the structure of the flavonoid. The position and total number of hydroxyl groups significantly influence the mechanism of antioxidant activity (Heim et al. 2002). The hydroxyl configuration of the B ring is the most important determinant of this activity (Burda and Oleszek 2001), whereas substitution of the A and C rings has little impact on the radical scavenging rate constants (Taubert 2003, Amic et al. 2007). These compounds serve as protection against ultraviolet radiation, pathogens, herbivores (Harborne and Williams 2000), and produce the coloring of certain flowers and fruits as well as wood. Many researchers have shown that the natural durability of certain woods is due to the presence of flavonoids. This is the case for dihydromorine and aromadendrine, which are contained in the extractives of *Acacia* essences (Schultz et al. 1995). Sirmah et al. (2009a) showed that the natural durability of *Prosopis juliflora* is due to the presence of -(-) mesquitol. Flavonoids are also used in cosmetics and prevent the oxidation of cells and the release of free radicals responsible for the alteration of cells that causes their aging.

Lignans.—Lignans are dimers consisting of two phenylpropane units (C6–C3) joined by a β–β bond at the C8 carbon (Umezawa 2003). They are classified into the following eight subgroups based on how oxygen is

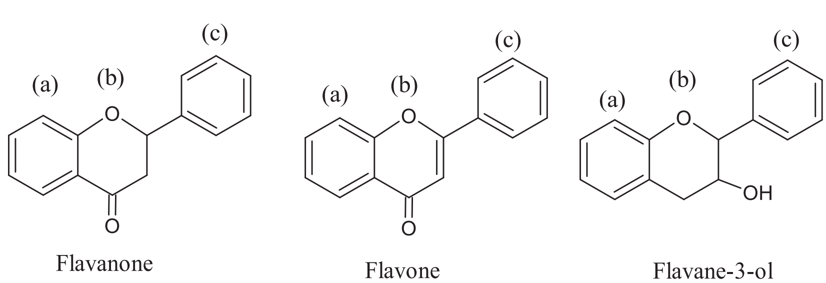


Figure 4.—Some families of flavonoids found in wood.

incorporated into the skeleton and the cyclization pattern: furofuran, furan, dibenzylbutane, dibenzylbutyrolactone, aryltetralin, arylnaphthalene, dibenzocyclooctadiene, and dibenzylbutyrolactol (Kebbi-Benkeder 2015). Lignans appear throughout the plant kingdom (Fig. 5). These molecules can be found in abundant quantities in the knots of wood (Holmbom et al. 2003, Smeds et al. 2012, Kebbi-Benkeder et al. 2014). In some species such as spruce, lignans can represent up to 25 percent of the dry mass of the knots while normal wood contains on average only 1 percent (Willför et al. 2006). In general, the concentration of lignans is often more significant in the nodes of branches subject to mechanical stresses and loads due to environmental conditions (e.g., snow, rain, and wind; Piispanen et al. 2008). Some lignans have shown toxicity to wood-destroying agents and are very difficult to break down.

The antifungal, antibacterial, and insecticidal properties of several lignans suggest that these compounds could serve in plant defense systems; moreover, they may play a role in the regulation of plant growth (Mijnsbrugge et al. 2000). For example, syringol is a lignin pyrolysis product of hardwoods, and is the main chemical responsible for smoke flavor (Bari et al. 2009). They may exhibit antifungal activities against fungi (Pandey and Pitman 2004), as in the case of different structures identified from the bark of obvata essence. Apart from these properties, lignans also have antitumor (matairesinol, podophyllotoxin, and steganacine), antimitotic (podophyllotoxin), antioxidant (nordihydroguaiaretic acid and sesaminol), and antiviral (podophyllotoxin) biological activities (Sirmah et al. 2009b). Lignans are a family of compounds that have been extensively studied for their interest in various fields, such as the pharmaceutical and agri-food fields, because of their phytoestrogenic effects (Hooper and Cassidy 2006, Lainé et al. 2007, Martins et al. 2011). In addition to these interests, lignans also have antioxidant properties (Lee et al. 2004, Zeng et al. 2014). Other lignans have antifungal properties (Kawamura et al. 2004, Céspedes et al. 2006).

Tannins.—Tannins are defined as ‘‘phenolic natural products that can precipitate proteins from their aqueous solutions’’ (Bruneton 2016, p. 555). Indeed, most tannins are astringent because they can complex reversibly or irreversibly with macromolecules such as proteins. They also have other biological properties including antioxidant activity and enzyme inhibition activity. Tannins are split into two groups according to their structure but also their biosynthetic origin: hydrolysable tannins and condensed tannins (proanthocyanidols; Fig. 6). Hydrolyzable tannins have often been overlooked because they are apparently more difficult to analyze than are condensed tannins. Hydrolysable tannins are synthesized by a wide variety of trees and many of them have been used as animal feed. They can occur in wood, bark, leaves, fruits, and galls (Kumar and Vaithiyanathan 1990, Naima et al. 2015). It should be noted that some species produce gallotannins or ellagitannins, while others produce complex mixtures containing gallo, ellagi, and condensed tannins. For example, *Acacia, Acer,* and Fagaceae are well known to have both condensed and hydrolysable tannins (Bate-Smith 1977, Ishimaru et al. 1987, Mueller et al. 1987).

Tannins are defined as plant-derived antinutrients because they can precipitate proteins, inhibit digestive enzymes, and reduce vitamin and mineral utilization. On the other hand, tannins have also been considered ‘‘health-promoting’’ components in plant-based foods and beverages. For example, tannins have been reported to possess anticarcinogenic and antimutagenic potentials, as well as antimicrobial properties. Several studies have reported on the antioxidant and antiradical activities of tannins (Amarowicz 2007). Some plants are known to be rich in tannins; this is the case of *Quercus* sp. woods, which are also widely used in the wine sector. Their woods are used to make barrels for aging wine and thus allow the creation of new aromas in wine (Zhang et al. 2015). Phlorotanin, main component of the brown algae *Ecklonia cava* used for tissue regeneration, is an inhibitor of human immunodeficiency virus type 1 (HIV-1), reverse transcriptase (RT), and protease (Ahn et al. 2004, Kim and Kim 2012). Tannin-furan foams, based on the co-reaction of condensed bark-derived tannins and thermoset furan polymers, have low thermal conductivity, are self-extinguishing, and have high fire resistance, which allowed their development for several industrial uses. One of their main drawbacks, however, is the absorption of water within the foam itself. Another problem is the rather friable surface, which is a definite drawback for some potential applications. The incorporation of fatty chains markedly decreased foam friability and increased water repellency in the bodies of these foams (Rangel et al. 2001, Sánchez et al. 2018).

Stilbenes.—Stilbenes (C6-C2-C6) are metabolites characterized by the presence of two benzene rings that are separated by an ethane or ethene bridge (Fig. 7). Of Z or E configuration, they can be free or associated with a glycoside. These compounds are mainly present in softwoods. This family of molecules has antioxidant properties (Välimaa et al. 2007), antifungals (Karppanen et al. 2007), and pharmacological and therapeutic uses (Parage 2013). They have antimicrobial and antifungal actions but would

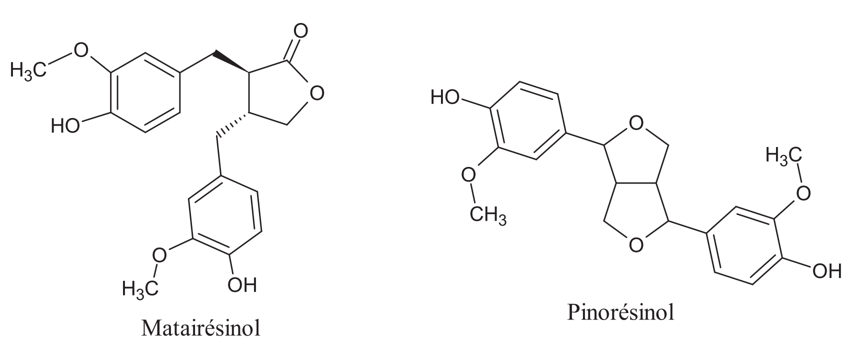


Figure 5.—Examples of lignans.

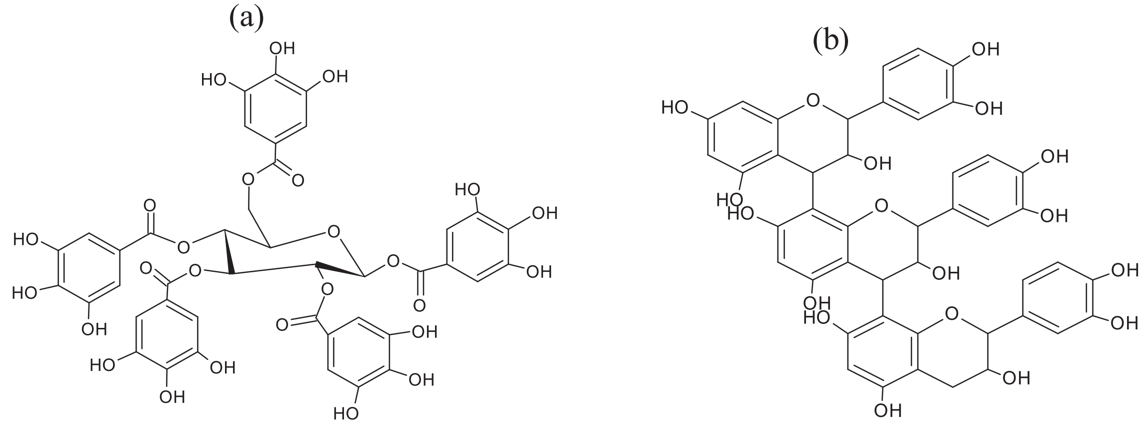


Figure 6.—Structures of hydrolysable tannin (a), condensed tannin (b).

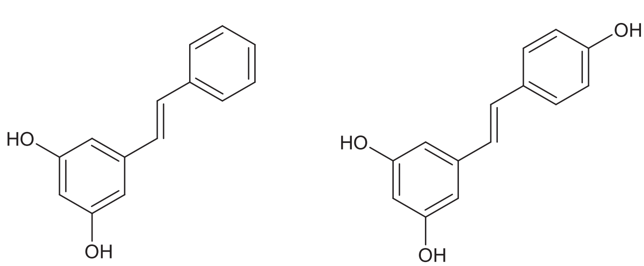
also be antiradical and metal chelators. The best-known stilbene is resveratrol, isolated from certain fruits such as grapes. This compound is widely used in cosmetology, as well as in the production of certain food supplements, because of its antioxidant and anti-inflammatory properties (Stevanovic and Perrin 2009, Bruneton 2016). Stilbenes are synthesized by the addition of one to three molecules of malonyl-CoA to cinnamic acids, which are derived from the phenylpropane biosynthetic pathway. They have a 1,2-diphenylethene structure and consist of a C6-C2-C6 backbone. Stilbenes have two benzene rings connected by two carbons that are themselves united by a double bond. In the tree, the proportion of stilbenes varies according to the part studied, and the toxicity varies according to their structures and the bacterial or fungal strains studied (Venalainen et al. 2004, Lee et al. 2005). Pinosylvine, resveratrol, and many other stilbenes have different functions; they act as free radical scavengers, biocides, and metal chelators (Sirmah et al. 2009b).

They play a role in fungicide and protection against insects. Different species of *Combretum*, rich in stilbenes, are resistant to termites. Stilbenes are important for resistance to wood rot fungi and research has been done on inducing stilbene biosynthesis by irradiating seedlings to give better wood resistance to biodegradation (Norin 1981). They strongly influence the technological properties of wood. Stilbenes such as pinosylvine and its mono or dimethylated forms, isolated from *Picea glauca*, *Pinus resinosa,* or *Pinus banksiana,* strongly inhibit the growth of white rots such as *Phanerochaete chrysosporiun* and *Trametes versicolor*, with a less significant inhibiting effect on brown rot fungi such as *Poria placenta*, *Gloeophyllum trabeum,* and *Neolentinus lepideus* (Célimène et al. 1999, Lu et al. 2015). Stilbenes are also widely used in pharmacology (e.g., resveratrol, which has significant cardioprotective and anticancer properties; Han and Li 2004, Wang et al. 2006).

Quinones.—Quinones are oxygenated compounds resulting from the oxidation of phenols. They have a distribution restricted to certain families (e.g., *Ebenaceae*, *Fabaceae*, *Juglandaceae*). Depending on the structure of their skeleton, they are classified into several categories of quinones such as benzoquinones, naphthoquinones, or anthraquinones (Bruneton 2016). Quinones have been found in the wood of certain tropical species, notably teak (*Tectona grandis*). Teak wood contains about 0.3 percent 2-methylanthraquinone (tectonic), which is a termite repellent and thus contributes to the natural durability of teak wood along with several other quinones such as naphthoquinone (Leyva et al. 1998, Thévenon et al. 2001; Fig. 8).

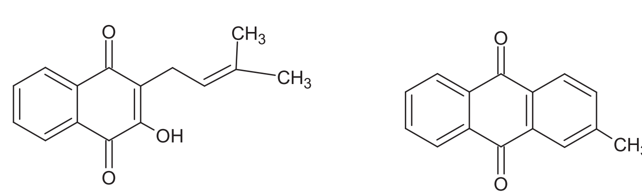
2-Methylanthraquinone isolated from the heartwood of teak wood, and catalponol and catalponone isolated from the heartwood of *Catalpa bignonioides,* have antitermite activities (Kokutse et al. 2006, Castillo and Rossini 2010). In the natural durability of teak wood, 4′,5′-dihydroxyepiisocatalponol plays an important role against fungal attack (Niamké et al. 2012). Niamké et al. (2012) showed that this compound was a fungicide capable of inhibiting the growth of *Trametes versicolor*. In the wood of *Diospyros virginiana*, 7-methyljuglone and its isolated derivatives are also endowed with termiticidal activity (Carter et al. 1978).

Alkaloids.—The term alkaloid derives from the word alkaline and describes a molecule with the behavior of a Lewis base. According to the definition of Pelletier (1983, p. 450), alkaloids are ‘‘cyclic organic compounds containing one or more nitrogen atoms of negative oxidation state and



Pinosylvine Resvératrol

Figure 7.—Structures of some stilbenes.



Lapachol 2-Methyl anthraquinone

Figure 8.—Structures of quinones found in teak wood.

having a limited distribution among living beings.'' The definition of the term alkaloid was recently extended by Hesse (2002) to all compounds possessing one or more nitrogen atoms, with varying degrees of basicity (Fig. 9). With >5,000 known compounds, alkaloids represent the most structurally diverse class of secondary metabolites, ranging from relatively simple molecules (such as coniine, a poison made by hemlock [*Conium maculatum*]) to incredibly complex compounds (such as batrachotoxin, a cardiotoxin and most dangerous neurotoxin in the animal world; Mann 1998). This chemical family has always attracted particular attention regarding the complexity of the structures and their potential in pharmacology. Widely used in pharmacy, some alkaloids are currently used as active ingredients in pharmaceutical specialties (Amirkia and Heinrich 2014). Many organic chemists have resorted to the organic synthesis of certain alkaloids, drawing inspiration from their chemical structures as they occur in nature. Since the 1960s, many alkaloids have been synthesized (Liu et al. 2016).

Functional properties

Alkaloids act either as a protective agent against fungi, insects, or even herbivores, as a source of nitrogen necessary for the development of the plant, as growth regulating agents similar to hormones, or as protective agents against ultraviolet radiation. Indeed, they are toxic to insects, paralyzing or killing insects that feed on them (Trematerra and Sciarretta 2002, Bouchelta et al. 2005). In medicine, alkaloids are used as major analgesics (morphine), antimalarial (quinine), to combat excess uric acid (colchicine), as a paralyzing substance (curare, caffeine), as poisons (strychnine, nicotine), as narcotics (cocaine, mescaline), as a cholinergic (pilocarpine), or as an anticancer (vinblastine, vincristine). They act directly on the nervous system with effects on consciousness and motor skills. The action on the nervous system can go as far as an antispasmodic, mydriatic, local anesthetic or analgesic, and narcotic action. *Cinchona* species contain quinoline alkaloids and indole alkaloids such as cinchonamine (Bruneton 2009).

All these alkaloids are said to have pronounced effects against *Plasmodium falciparum*. Similarly, the bark of *Alstonia boonei*, the leaves *of Chromolaena odorata* and *Carica papaya* also contain indole alkaloids; hence, there is interest in use of them in the fight against malaria. N'Guessan et al. (2009) already reported the importance of indole alkaloids from *Chromolaena odorata* in this fight. Indole alkaloids have less effect than quinoline alkaloids in the fight against malaria but do not have side effects (such as ringing in the ears; Souleymane 2005). *Nicotiana tabacum* and *Capsicum annuum* are regularly prescribed against intestinal worms and contain tropane alkaloids and capsaine, respectively. These alkaloids, when used to remedy stomach aches, are reputed to reduce gastrointestinal spasms and produce laxative effects. They increase intestinal peristalsis (Nacoulma-Ouédraogo 1996, N'Guessan et al. 2009). In addition, *Capsicum frutescens* prescribed for lower back pain contains capsaine, which N'Guessan et al. (2009) described as having antirheumatic properties. Pyrrolizidine alkaloids from *Hibiscus esculentus* and indole alkaloids (agroclavine) from *Rauvolfia vomitoria* exert an oxytocic effect and are therefore useful in facilitating childbirth (N'Guessan et al. 2009). In addition, *Rauvolfia vomitoria* prescribed for the treatment of foot edema contains punarnavine (Kerharo and Adam 1974), which causes a marked and persistent increase in blood pressure with strong diuresis via action on the renal epithelium. In addition, reserpine from *Rauvolfia vomitoria* has sedative properties. This drug is used to treat states of anxiety and mentally disturbed patients, hence its empirical use in the treatment of epileptic seizures (N'Guessan et al. 2009). The effect against migraine of *Ageratum conyzoides* would be due to alkaloids, probably of the ergotamine type (Yinyang et al. 2014). Caffeine present in *Cola acuminata*, *Coffea robusta*, *Coffea arabica*, *Camellia sinensis*, and *Theobroma cacao* has competitive antagonistic effects of adenosine receptors. It is a neuromodulator limiting the release of the main excitatory neurotransmitters. This is how it causes acceleration of the heart rate with the possibility of palpitations, stimulation of the central nervous system with increased vigilance and sometimes anxiety, bronchodilation, or more precisely antagonistic effect of bronchoconstriction in asthmatics where adenosine seems to play a major role (Debry 1993). The properties of *Phyllanthus amarus*, *Myristica fragrans*, and *Annona muricata* against heartburn would be due to the presence of alkaloids, which would reduce pain and acidity of the stomach in patients suffering from gastric ulcers. Yohimbine, an indoloterpene alkaloid from the bark of *Pausinystalia johimbe* is one of the only natural aphrodisiacs known to man and the most powerful. It

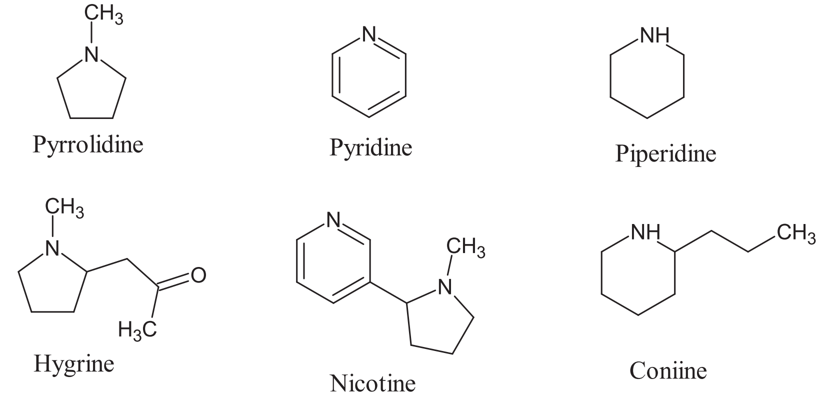


Figure 9.—Examples of alkaloids with main structural types.

has a competitive antagonistic effect on adrenergic receptors and causes strong psychic stimulation, an intensification of sexual emotions, a slight change in perceptions that can cause weak hallucinations, and sometimes spontaneous erections in males (Aubry 2012).

Fields of application of extractives

There are many possibilities for recovering wood extractives, which could then be used in the fields of pharmacology, perfumery, cosmetics, agrifood, agriculture (Mounguengui 2008, Huang et al. 2009). In the rest of the work, we mainly address the areas of application that have aroused interest in recent decades.

Food industry

Lipid foods are less resistant to oxygen oxidation during storage. Lipid oxidation is the major cause of deterioration of foods containing fat, and such foods must be preserved with antioxidants. An antioxidant can be defined according to Halliwell (1994) as an entity that, present in low concentration, can reduce, delay, or prevent oxidative destruction of biomolecules. The antioxidant activity can be evaluated by several methods: ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) or TEAC (Trolox equivalent antioxidant capacity) test (Miller et al. 1993); ORAC (oxygen radical absorbance capacity) test (Glazer et al. 1993); DPPH (2,2-diphenyl-1-picrylhydrazyl radical) test (Brand-Williams et al. 1995); Methyl linoleate test; FRAP (ferric reducing antioxidant power) test (Benzie and Strain 1999). Antioxidants can be provided naturally by food (fruits, vegetables, tea, red wine, coffee, and cocoa). However, in the food industry the synthetic antioxidants officially authorized and used—namely Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tertiary butyl hydroquinone (TBHQ), and propyl gallate (PG) (Branen 1975)—are carcinogenic and accumulate in the body (Linderschmidt et al. 1986, Kalamouni 2010). When confronted with this problem of toxicity of synthetic antioxidants, less toxic sources of natural antioxidants would be a better alternative. Among the natural antioxidants, we can cite the phenolic compounds that are found in almost all plants, which can stop the exponential development of lipid radicals to form stable phenolic radicals while breaking the oxidation chain reactions (Diouf 2003). Many publications describe natural antioxidants (Pietta 2000, Moure et al. 2001). These natural compounds are already finding their applications in the food industry, we can cite, e.g., the case of ascorbic acid (vitamin C), tocopherol (related to vitamin E), sesame oil, and olive oil (Taga et al. 1984, Altarejos et al. 2005, Pérez-Bonilla et al. 2006, Kalamouni 2010). Anthocyanins are widely used in the food industry and cosmetics because of their coloring properties and their ability to trap free radicals.

Agriculture

In addition to their antioxidant properties, wood waste extracts can also have several applications, such as fungicide, fungistatic, insecticide, nematicide, herbicide, bactericide, bacteriostatic; hence, there is growing interest in using wood wastes in agriculture via the extractives contained therein. Lall et al. (2006) found that sitosterols have good inhibitory activity against *Aspergillus niger*, *Cladosporium cladosporioides*, and *Phytophthora* sp. *fung*. Pterocarpanes are flavonoids with good antifeedant activity and could be used in agriculture for protection against pests. The antifungal activity of plant sitosterol has been demonstrated by Mbambo et al. (2012). The biocidal particularity of certain terpenes such as resin acids or tropolones has biocidal properties (Roussel-Bousta 2000), which could be used in agriculture for protection against pests. Unlike organophosphorus or organochlorine biocides used in agriculture, which have persistent and dangerous harmful effects on human health, greener alternatives to these carcinogenic compounds would be a huge step forward in protecting the environment and consumer health. Several authors have shown that initially durable wood becomes more susceptible to lignivorous fungi or termites after undergoing extraction treatments with organic and/or aqueous solvents (Oliveira et al. 2010, Kirker et al. 2013). This fragility of the wood after extracting the extractives contained therein would facilitate faster degradation of wood waste in the environment and would make it less risky to use as compost in agriculture.

Pharmaceutical

Phytosterols (β-Sitosterol, stigmasterol) present in the wood of *Coula edulis* are very important molecules that are part of the sterol family (Lercker and Rodriguez-Estrada 2000). These molecules have important biological properties. Phytosterols are biogenetically and structurally close to steroids, which are biologically active. Numerous studies have shown that sterols and triterpene alcohols have anticancer properties on colon, lung, and prostate cancer (Raicht et al. 1980, Smith et al. 1996, Awad et al. 2004, Woyengo et al. 2009). Stigmasterol has antidiabetic, anticancer, antidiarrheal, and antiviral properties (Venkata et al. 2012). Moreover, sitosterol is the compound that best represents phytosterols, belonging to the class of sterol molecules (Liswidowati et al. 2001). Hydroxymatairesinol, an extract present from Norway spruce (*Picea abies*) knots, is used as a food supplement for the fight against breast cancer and in treatment of the prostate (Stevanovic and Perrin 2009). In pharmacy and nutraceuticals, aspirin, which is a derivative of salicylic acid extracted from willow bark (*Salix* sp.), is used as an antipyretic, anti-inflammatory, analgesic, and anticoagulant. Triterpenes such as lupeol, botulin, and betulinic acid extracted from the bark of yellow and white birch are used for their anticancer activities. Ginko extract (*Ginkgo biloba*) is rich in polyphenols and is very effective against memory disorders, peripheral vascular deficiencies, muscle degeneration, tinnitus, vertigo, and diabetic retinopathy (Qa'dan et al. 2010). Extracted from the bark of cinchona, quinine is used in pharmacies as an antimalarial. Taxol was isolated from the bark of the Pacific yew (*Taxus brevifolia*) in the 1970s, and is used for its anticancer properties. Secondary metabolites from natural products are potential sources of acetylcholinesterase inhibitors, which are key enzymes in the treatment of many neurodegenerative diseases. Reported activities of *Beilschmiedia insignis* alkaloids showed that the five aporphine alkaloids, namely isocorydine (1), norisocorydine (2), (+)-laurotetanine (3), (+)-N-methyllaurotetanine (4), and (+)-boldine (5), exhibit acetylcholinesterase inhibitory activities with percent inhibition values ranging from 44.9 to 74.5 percent (Wan Mohd et al. 2021).

Cosmetic

Linalool and santalol extracted from rosewood (*Aniba duckei*: Lauraceae) and sandalwood (*Santalum album*: Santalacae), respectively, are used for perfumes in cosmetics. The composition of make-up products is often noted because, in addition to certain products that benefit from organic certifications, make-up is essentially based on synthetic ingredients such as silicones, talc, and dyes. The coloring and natural origins of certain wood extractives could make them useful as alternatives to the synthetic dyes used in the composition of make-up products.

Industrial

Among all the extractives, the most studied and those that often find industrial applications are polyphenols (Stevanovic and Perrin 2009, Fernandez-Agullo et al. 2015). For years, tannins have been used to make green adhesives, flame-retardant foams, dyes, and for tanning leather. In the rubber tree (*Castilla elastica*), the extracts (polyterpenes) make it possible to obtain the latex for the manufacture of natural rubber (Stevanovic 2011). Extract of balsam fir (*Abies balsamea*) containing juvabione is used for inhibition of beetle juvenile hormone. Some species have extractives that inhibit the growth of wood weathering agents (bacteria, termites, and fungi; Maranhão et al. 2013), and teak wood contains large amounts of quinones responsible for durability natural to this wood. The extract of this essence inhibits the growth of *Trametes versicolor* (white rot fungi) at concentrations of 58 mg/mL (Niamké et al. 2012).

Interest of wood waste

Côte d'Ivoire is a timber-producing and -exporting country. Côte d'Ivoire exported 315,114.948 m^3 of wood according to the 2017 activity report of the Department of Forest Production and Industry (DPIF 2017) of the Ministry of Water and Forests. In Côte d'Ivoire, 387 Forest Exploitation Perimeters (PEF) are defined, constituting the rural domain, and covering an area of approximately 14,210,096 ha (44 percent of the national territory), for a theoretical annual exploitation quota estimated at 3,553,846.15 m^3. During 2017, of the 387 existing PEFs, 377 PEFs were allocated, of which 365 (97%) were authorized for operation. The volumes of wood taken from these logging perimeters (Table 1), from primary processing companies (e.g., felling, sawing, slicing, peeling) to third-level processing companies (e.g., carpentry), generate wood residues that have no value for these companies and are abandoned in our environment as waste. This wood waste is available in large quantities in our environments and is a great source of bioactive molecules that we could extract and recover upstream before any energy recovery as biofuels, with the aim of replacing petrochemical products as shown by numerous studies (Fernandez-Agullo et al. 2015, Meullemiestre et al. 2016, Bostyn et al. 2018, Santos et al. 2019, Das et al. 2020, Zhou et al. 2020, Zwingelstein et al. 2020). Taking account of extractives molecules in wood waste would add value to this waste, thus making it possible to regulate certain aspects of insalubrity by reducing environmental pollution. This would also make it possible to reduce the pressure on very resistant, highly prized noble species by giving durability to species that are less valuable, or those that are impregnable and not very durable (Onuorah 2000, Brocco et al. 2017, Mbakidi-Ngouaby et al. 2018, Kadir and Hale 2019, Eller et al. 2020, Kadir and Hassan 2020, Wu et al. 2020, Zulfiqar et al. 2020). Thus, wood waste constituting the end of life for forest industry products could be the raw material of a so-called extractives sector, very little explored, thus inducing a circular economy with value chains. The stakes are high and will ultimately lead to a reduction in the environmental impact of forestry activity (Wang et al. 2011, Wen et al. 2019).

Table 1.—Average volume of wood harvested per Forest Exploitation Perimeters (PEF) calculated by Initiatives for Community Development and Forest Conservation (IDEF) based on figures from the 2016 Department of Forest Production and Industry (DPIF) report.

Forest regions	Volumes (m^3)	No. of PEFs in operation	Average volume taken per PEF (m^3)
Bondoukou	111,249.793	12	9,270.812
Yamoussoukro	292,840,.412	39	7,508.128
Bouake	58,169.043	8	7,271.130
Seguela	15,939.05	3	5,313.016
Abidjan	163,447.342	35	466.981
Man	215,671.725	44	4,901.630
Daloa	116,703.599	25	4,668.143
Gagnoa	128,438.659	30	4,281.288
Abengourou	64,716.481	19	3,406.130
San-Pedro	37,046.369	15	2,469.757

Conclusion

Wood contains extractives compounds, the quantity of which varies from one tree to another and from one region to another and according to the age of the tree. These extractives can be extracted by suitable techniques and solvents. They are natural and have chemical and biological properties that can be exploited and have been exploited to date in various fields and sectors of activity. The availability of wood waste in developing countries whose economy is largely based on agriculture, such as Côte d'Ivoire, is an opportunity for its development in view of the varied content and composition of extractives from this waste. The multiple possible uses known to date and the renewable and natural nature of this resource are attracting more interest from researchers. The establishment of an ''extractives'' sector would be interesting especially because it would be an added value for logging on the one hand, and on the other hand would ensure better management of forests and contribute to stronger environmental resilience.

Acknowledgments

I am grateful to all of those with whom I have had the pleasure to work during this project. Each of the members has provided me extensive personal and professional guidance about both scientific research and life in general.

Literature Cited

Aboubakar Dandjouma, A. K., C. Tchiegang, and M. Parmentier. 2008. Evolution of some physico-chemical quality parameters of the oil from the fruit pulp of *Canarium schweinfurthii* Engl. during storage. *Int. J. Biol. Chem. Sci*. 2(3):249–257. https://doi.org/10.4314/ijbcs.v2i3.39760

Ahn, M. J., K. D. Yoon, S. Y. Min, J. K. Lee, J. H. Kim, T. G. Kim, S. H. Kim, N. G. Kim, H. Huh, and J. Kim. 2004. Inhibition of HIV-1 reverse transcriptase and protease by phlorotannins from the brown alga *Ecklonia cava*. *Biol. Pharm. Bull*. 27:544–547.

Alén, R., P. Oesch, and E.Kuoppala.1995. Py-GC/AED studies on the thermochemical behavior of softwood. *J. Anal. Appl. Pyrol*. 35:259–265.
Ali, A., A. Criscuoli, F. Macedonio, and E. Drioli. 2019. A comparative analysis of flat sheet and capillary membranes for membrane distillation applications. *Desalination* 456(15):1–12. https://doi.org/10.1016/j.desal.2019.01.006
Altarejos, J., S. Salido, M. Perez-Bonilla, P. J. Linares-Palomino, T. A. Van Beek, M. Nogueras, and A. Sanchez. 2005. Preliminary assay on the radical scavenging activity of the olive wood extracts. *Fetoterapia* 76:348–351.
Amarowicz, R. 2007. Tannins: new natural antioxidants? *Eur. J. Lipid Sci. Technol*. 109:549–551.
Amic, D., D. Davidovic-Amic, D. Beslo, V. Rastija, B. Lucic, N. Trinajstic. 2007. SAR and QSAR of the antioxidant activity of flavonoids. *Curr. Med. Chem*. 14:827–845.
Amirkia, V., and M. Heinrich. 2014. Alkaloids as drug leads—A predictive structural and biodiversity-based analysis. *Phytochem. Lett*. 10:xlviii–liii.
Amusant, N. 2003. Natural durability and color of Guyana wood: Measurement, variability, chemical determinism. Applications to *Dicorynia guianensis* (Angelica), *Sextonia rubra* (Grignon), *Eperua falcata* (Wapa) and *Eperua grandiflora* (Wapa courbaril). Thèse de Doctorat. Forest Sciences and Wood Sciences, National School of Rural, Water and Forests Engineering, Nancy, France. 228 pp.
Amusant, N., C. Moretti, B. Richard, E. Prost, J. M. Nuzillard, and M. F. Thevenon. 2007. Chemical compounds from *Eperua falcata* and *Eperua grandiflora* heartwood and their biological activities against wood destroying fungus (*Coriolus versicolor*). *Holz Roh Werkstoff* 65:23–28.
Arima, H., H. Ashida, and G. Danno. 2002. Rutin-enhanced antibacterial activities of flavonoids against *Bacillus cereus* and *Salmonella enteritidis*. *Biosci. Biotech*. *Biochem*. 66 (5):1009–1014.
Arnason, T., R. J. Hebda, and T. Johns. 1981. Use of plants for food and medicine by Native Peoples of eastern Canada. *Can. J. Bot*. 59:2189–2325.
Aubry, P. 2012. Intoxications par les plantes toxiques dans les zones tropicales et inter tropicales. https://www.doc-developpement-durable.org/file/Culture/Plantes-Medicinales-Aromatiques/intoxication_par_plante.pdf. Accessed June 8, 2023
Awad, A. B., J. Toczek, and C. S. Fink. 2004. Phytosterols decrease prostaglandin release in culture P388D1/MAB macrophages. *Prostaglandins Leukot*. *Essent. Fatty Acids* 70:511–520.
Barbosa, A. P., C. S. D. Nascimento, and J. W. D. Morais. 2007. Studies on the antitermitic properties of wood and bark crude extracts of forest species from Central Amazonian, Brazil. *Acta Amazonica* 37(2):213–218.
Bari, M. A., G. Baumbach, B. Kuch, and G. Scheffknecht. 2009. Wood smoke as a source of particle-phase organic compounds in residential areas. *Atmos. Environ*. 43:4722–4732.
Bate-Smith, E. C. 1977. Astringent tannins of *Acer* species. *Phytochemistry* 16:1421–1426.
Benzie, I. F. F. and J. J. Strain. 1999. Ferric reducing antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration. *Methods Enzymol*. 299:15–27.
Bostyn, S., E. Destandau, J. P. Charpentier, V. Serrano, J. M. Seigneuret, and C. Breton. 2018. Optimization and kinetic modelling of robinetin and dihydrorobinetin extraction from *Robinia pseudoacacia* wood. *Ind. Crops Prod*. 126 (April):22–30. https://doi.org/10.1016/j.indcrop.2018.09.049
Bouchelta, A., A. Boughdad, and A. Blenzar. 2005. Biocidal effects of alkaloids, saponins and flavonoids extracted from *Capsicum frutescens* L. (Solanaceae) on *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). *Biotech. Agron*. *Soc. Environ*. 9(4):259–269.
Brand-Williams, W., M. E. Cuvelier, and C. Berset. 1995. Use of free radical method to evaluate antioxidant activity. *Lebensm. -Wiss*. *Technol*. 28:25–30.
Branen, A. L. 1975. Toxicology and biochemistry of butylated hydroxyanisole and butylated hydroxytoluene. *J. Am. Oil Chem. Soc*. 52:59–63.
Brendler, T., J. N. Eloff, A. Gurib-Fakim, and L. D. Phillips. 2010. African herbal pharmacopoeia. Graphic Press Ltd., Mauritus.
Brocco, V. F., J. B. Paes, L. G. Costa, S. Brazolin, and M. D. C. Arantes. 2017. Potential of teak heartwood extracts as a natural wood preservative. *J. Clean*. *Prod*. 142:2093–2099. https://doi.org/10.1016/j.jclepro.2016.11.074
Bruneton, J. 2009. Pharmacognosie—Phytochimie, Plantes Médicinales. 4e édition, revue et augmentée. Tec & D—c - Éditions Médicales Internationals, Paris. 1288 pp.
Bruneton, J. 2016. Pharmacognosie. Phytochimie. Plantes Médicinales, 5ème éditio—. Lavoisier, Paris. 1487 pp.
Bugrein, H. and S. M. Bujassoum.2016. Genotype and phenotype correlation of breast cancer in BRCA carriers and noncarriers. *In:* Qatar Foundation Annual Research Conference Proceedings Volume 2016 (1). Hamad bin Khalifa University Press HBPP1674, Doha, Qatar. https://doi.org/10.5339/qfarc.2016.HBPP1674
Burda, S. and W. Oleszek. 2001. Antioxidant and antiradical activities of flavonoids. *J. Agric. Food Chem*. 49: 2774–2779.
Cao, G. H., H. M. Alessio, and R. G. Cutler. 1993. Oxygen-radical absorbance capacity assay for antioxydants. *Free Radical Biol. Med*. 14:303–311.
Castillo, L. and C. Rossini. 2010. Bignoniaceae metabolites as semiochemicals. *Molecules* 15:7090–7105.
Carter, F. L., A. M. Garlo, and J. B. Stanley. 1978. Termiticidal components of wood extracts: 7-methyljuglone from Diospyros virginiana. *J. Agric. Food Chem*. 26(4):869–873.
Célimène, C. C., J. A. Micales, L. Ferge, and R. A. Young. 1999. Efficacy of pinosylvins against white-rot and brown-rot fungi. *Holzforschung* 53:491–497.
Céspedes, C. L., J. G. Avila, A. M. García, J. Becerra, C. Flores, P. Aqueveque, M. Bittner, M. Hoeneisen, M. Martinez, and M. Silva. 2006. Antifungal and antibacterial activities of *Araucaria araucana* (Mol.) K. Koch heartwood lignans. *J. Biosci*. 61:35–43.
Coelho, D., G. Marques, A. Gutierrezz, A. J. D. Silvestre, and J. C. del Rio. 2007. Chemical characterization of the lipophilic fraction of giant reed (*Arundo donax*) fibres used for pulp and paper manufacturing. *Ind. Crops Prod*. 26:229–236.
Dahouenon-Ahoussi, E., T. S. Djenontin, D. R. M. Codjia, F. P. Tchobo, A. G. Alitonou, A. F. Dangou, and D. C. K. Sohounhloue. 2012. Fruit morphology and some physical and chemical characteristics of the oil and cakes of *Irvingia gabonensis* (Irvingiaceae). *Int. J. Biol. Chem. Sci*. 6(5):2263–2273. DOI: https://doi.org/10.4314/ijbcs.v6i5.32
Das, A. K., M. N. Islam, M. O. Faruk, M. Ashaduzzaman, and R. Dungani. 2020. Review on tannins: Extraction processes, applications and possibilities. *South Afr. J. Bot*. 135:58–70. https://doi.org/10.1016/j.sajb.2020.08.008
Da Silva, P. M., C. Gauche, L. V. Gonzaga, A. C. O. Costa, R. Fett. 2016. Honey: Chemical composition, stability and authenticity. *Food Chem*. 196:309–323.
Debry, G. 1993. Le Café et la Santé. John Libbey Eurotext, Paris.
Diouf, P. N. 2003. Étude comparative de méthodes de mesure d' l'activité antioxydante. Applications aux extractibles de bois. Liens avec la stabilité de la couleur du bois. Thèse Doctorat. Université Henri Poincaré, Nancy, France. 144 pp.
Diouf, P. N., T. Stevanovic, and Y. Boutin. 2009. The effect of extraction process on polyphenol content, triterpene composition and bioactivity of yellow birch (*Betula alleghaniensis* Britton) extracts. *Ind. Crops Prod*. 30(2):297–303.
Eller, F. J., G. T. Kirker, M. E. Mankowski, W.T. Hay, D. E. Palmquist. 2020. Effect of burgundy solid extracted from Eastern red cedar heartwood on subterranean termites and wood-decay fungi. *Ind. Crops Prod*. 144 (June 2019):112023. https:// doi.org/10.1016/j.indcrop.2019.112023
Espitalier, X. 2014. Intérêt de la *Griffonia simplicifolia*, *Mucuna pruriens* et de *Rhodiola rosea* dans le traitement de la dépression. Thèse de doctorat d'Etat en pharmacie. Université de Lorraine, Nancy, France.
Fengel, D. and G. Wegner. 1989. Wood—Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin.
Fernandez-Agullo, A., M. S. Freire, and J. González-Alvarez. 2015. Effect of the extraction technique on the recovery of bioactive compounds from eucalyptus (*Eucalyptus globulus*) wood industrial

wastes. *Ind. Crops Prod*. 64:105–113. https://doi.org/ 10.1016/j.indcrop.2014.11.031

Gamboa-Gómez, C. I., L. E. Simental-Mendía, R. F. González-Laredo, E. J. Alcantar-Orozco, V. H. Monserrat-Juarez, J. C. Ramírez-Espana, J. A. Gallegos-Infante, M. R. Moreno-Jiménez, and N. E. Rocha-Guzmán. 2017. In vitro and in vivo assessment of anti-hyperglycemic and antioxidant effects of oak leaves (*Quercus convallata* and *Quercus arizonica*) infusions and fermented beverages. *Food Res. Int*. 102 (September):690–699. https://doi.org/10.1016/j.foodres.2017.09.040

Gandini, A. and M. N. Belgacem. 2002. La chimie des substances renouvelables. *Actual. Chim*. 6–14. https://new.societechimiquedefrance.fr/wp-content/uploads/2019/12/2002-nov-dec-258-259-NT2-Gandini1.pdf. Accessed May 18, 2023.

Garcia, R., E. S. S. Alves, M. P. Santos, G. M. F. Viégas Aquije, A. A. R. Fernandes, R. B. Dos Santos, J. A. Ventura, and P. M. B. Fernandes. 2008. Antimicrobial activity and potential use of monoterpenes as tropical fruits preservatives. *Braz. J. Microbiol*. 39:163–168. https://doi.org/10.1590/s1517-83822008000100003 2

Gierlinger, N., D. Jacques, M. Grabner, R. Wimmer, M. Schwanninger, P. Rozenberg, and L. E. Pâques. 2004. Colour of larch heartwood and relationships to extractives and brown-rot decay resistance. *Trees* 18:102–108.

Glazer, C., H. M. Alessio, and R. G. Cutler. 1993. Oxygen-radical absorbance capacity assay for antioxidants. *Free Radic*. *Biol. Med*. 14(3):303–311.

Halliwell, B. 1994. Free radicals, antioxidant and human disease: Curiosity, cause or consequence. *Lancet* 344:721–724.

Haluk, J. P. and P. Jodin. 1994. Composition chimique du bois. *In:* Le Bois Matériau d'Ingénierie. Edition ARBOLOR 433:53–88.

Haluk, J. P. and C. Roussel. 2000. Durabilité naturelle du Red Cedar et application des biotechnologies végétales dans le domaine de la préservation du bois. *Ann. Forest Sci*. 57:819–829.

Han, D. H. and R. H. Li. 2004. Mechanisms of cardiovascular protection by resveratrol. *J. Med. Food* :290–298.

Harborne, B. J. and A. C. Williams. 2000. Review in advances in flavonoids research since 1992. *Phytochemistry* 55:481–504.

Haslam, E. 1998. Practical Polyphenols. Cambridge University Press, Cambridge, England. 422 pp.

Hawley, L. F., L. C. Fleck, and C. A. Richards. 1924. The relation between durability and chemical composition in wood. *Ind. Eng. Chem*. 16(7):699–700. https://doi.org/10.1021/ie50175a015

Heim, K. E., A. R. Tagliaferro, and D. J. Bobilya. 2002. Flavonoid antioxidants: Chemistry, metabolism and structure–activity relationships. *J. Nutr. Biochem*. 13:572–584.

Hesse, M. 2002. Alkaloids: Nature's Curse or Blessing? Wiley-VCH, Weinheim, Baden-Württemberg, Germany.

Hillis, W. E. 1975. The role of wood characteristics in high temperature drying. *J. Inst. Wood Sci*. 7:60–65.

Holmbom, B., C. Eckerman, P. Eklund, J. Hemming, L. Nisula, M. Reunanen, R. Sjöholm, A. Sundberg, K. Sundberg, and S. Willför. 2003. Knots in trees—A new rich source of lignans. *Phytochem. Rev*. 2:331–340.

Hon, D. N-S., and N. Shiraishi. 2000. Wood and Cellulosic Chemistry (CRC Press). Marcel Dekker, Inc., New York and Basel, Switzerland. 914 pp.

Hon, D. N-S., and N. Shiraishi. 2001. Wood and Cellulosic Chemistry. Second edition, revised and expanded. Marcel Dekker, Inc., New York and Basel, Switzerland. 914 pp.

Hooper, L. and A. Cassidy. 2006. A review of the health care potential of bioactive compounds. *J. Sci. Food Agric*. 86:1805–1813.

Huang, Z., K. Hashadi, R. Makino, F. Kawamura, S. Kuniyoshi, and K. O. S. Ryuichiro. 2009. Evaluation of biological activities of extracts from 22 African tropical wood species. *J. Wood Sci*. (55):225–229.

Ishimaru, K., G. I. Nonaka, I. Nishioka. 1987. Tannins and related compounds. LV Isolation and characterization of acutissimins A and B, novel tannins from *Quercus* and *Castanea* species.

Chem. Pharm. Bull. 35:602–610.

Jodin, P. 1994. Le Bois Matériau d'Ingénierie. Association pour la Recherche sur le Bois en Lorraine, Nancy, France. pp. 433.

Kadir, R. and M. Hale. 2019. Biocidal potential of the extractives of four Malaysian timbers against subterranean termites and wood decay fungi. *Eur. J. Wood Wood Prod*. 77 (1):147–155. https://doi.org/10.1007/s00107-018-1361-5

Kadir, R. and B. Hassan. 2020. Toxicity and repellent effects of wood extractives of five Malaysian wood species on Asian subterranean termite *Coptotermes gestroi* Wasmann. *Eur. J. Wood Wood Prod*. 78:1249–1262. https://doi.org/10.1007/s00107-020-01592-z

Kähkönen, M. P., A. I. Hopia, H. J. Vuorela, J. P. Rauha, K. Pihlaja, T. S. Kujala, and M. Heinonen. 1999. Antioxidant activity of plant extracts containing phenolic compounds. *J. Agric. Food Chem*. 47:3954–3962.

Kalamouni, E. C. 2010. Caractérisations chimiques et biologiques d'extraits de plantes aromatiques oubliées de Midi-Pyrénées. Thèse de Doctorat soutenue à l'Université de Toulouse, France 263 pp.

Karonen, M., M. Hämäläinen, R. Nieminen, K. D. Klika, J. Loponen, V. V. Ovcharenko, E. Moilanen, and K. Pihlaja. 2004. Phenolic extractives from the bark of *Pinus sylvestris* L. and their effects on inflammatory mediators nitric oxide and prostaglandin E2. *J. Agric. Food Chem*. 52:7532–7540.

Karppanen, O., M. Venäläinen, A. M. Harju, S. Willför, S. Pietarinen, T. Laakso, and P. Kainulainen. 2007. Knotwood as a window to the indirect measurement of the decay resistance of Scots pine heartwood. *Holzforschung* 61:600–604.

Kawamura, F., S. Ohara, and A. Nishida. 2004. Antifungal activity of constituents from the heartwood of Gmelina arborea: Part 1. Sensitive antifungal assay against Basidiomycetes. *Holzforschung* 58:189–192.

Kebbi-Benkeder, Z. 2015. Biodiversité interspécifique et intraspécifique des extractibles nodaux. Sylviculture, foresterie. AgroParisTech. ffNNT: 2015AGPT0072f https://pastel.archives-ouvertes.fr/tel-01374613/file/51933_KEBBI_2015_archivage.pdf. Accessed May 18, 2023.

Kebbi-Benkeder, Z., F. Colin, S. Dumarçay, and P. Gérardin. 2015. Quantification and characterization of knotwood extractives of 12 European softwood and hardwood species. *Ann. Forest Sci*. 72:277–284.

Kerharo, J. and J. G. Adam. 1974. La pharmacopée sénégalaise traditionnelle. Plantes Médicinales et Toxiques. *J. Agric. Trad. Bot. Appl*. 21:76–77.

Kim, M. and G. Kim. 2012. Electrospun PCL/phlorotannin nanofibres for tissue engineering: Physical properties and cellular activities. *Carbohydr. Polym*. 90:592–601.

Kirker, G. T., A. B. Blodgett, R. A. Arango, P. K. Lebow, and C. A. Clausen. 2013. The role of extractives in naturally durable wood species. *Int. Biodeterior*. *Biodegrad*. 82:53–58.

Kokutse, A. D., A. Stokes, H. Bailleres, K. Kokou, and C. Baudasse. 2006. Decay resistance of Togolese teak (*Tectona grandis* L.f) heartwood and relationship with colour. *Trees* 20:219–223.

Krutul, D. 1992. The effect of extractives substances soluble in the alcohol–benzene mixture and in alkalies on some hygroscopic properties of birch wood. *Forestry Wood Technol*. 43:93–99.

Kumar, P. S., T. Praveen, and J. Banweer. 2010. A review on *Griffonia simplicifolia*—An ideal herbal antidepressant. *Int. J. Pharm. Life Sci*. 1(3):174–181.

Kumar, R., and S. Vaithiyanathan. 1990. Occurrence, nutritional significance and effect on animal productivity of tannins in tree leaves. *Anim. Feed Sci. Technol*. 30 (1–2):21–38.

Lacandula, J. O. 2002. Variations in the physics of wood of selected Philippine tree species as a function of extractive content. *CMU J. Sci*. 10 (1):69–111.

Lainé, E., C. Hano, and F. Lamblin. 2007. Les lignanes phytoestrogènes du lin, sont-ils des bienfaiteurs méconnus? *Phytothérapie* 5:121–128.

Lall, N., O. Weiganand, A. A. Hussein, and J. J. M. Meye. 2006. Antifungal activity of naphthoquinones and triterpenes isolated from the root bark of *Euclea natalensis*. *S. Afr. J. Bot*. 72:579–583.

Lee, K. H., S. G. Wi, P. Adya, and S. Y. S. Kim. 2004. Micromorphological characteristics of decayed wood and laccase produced by the brown-rot fungus *Coniophora puteana*. *J. Wood Sci*. 50:281–284.

Lee, S. K., H. J. Lee, H. Y. Min, E. J. Park, K. M. Lee, Y. H. Ahn, Y. J. Cho, and J. H. Pyee. 2005. Antibacterial and antifungal activity of pinosylvin, a constituent of pine. *Fitoterapia* 76(2):258–260.

Lercker, G. and M. Rodriguez-Estrada. 2000. Chromatographic analysis of unsaponifiable compounds of olive oils and fat-containing foods. *J. Chromatogr. A* 881:105–129.

Leyva, A., D. R. Dimmel, and G. S. Pullman. 1998. Teak extract as catalyst for the pulping of loblolly pine. *Tappi J*. 81: 237–240.

Linderschmidt, R., A. Trylka, M. Goad, and H. Witschi. 1986. The effects of dietary butylated hydroxytoluene on liver and colon tumor development in mice. *Toxicology* 38:151–160.

Lišková, J., T. E. L. Douglas, J. Beranová, A. Skwarczyńska, M. Božič, S. K. Samal, Z. Modrzejewska, S. Gorgieva, V. Kokol, and L. Bačáková. 2015. Chitosan hydrogels enriched with polyphenols: Antibacterial activity, cell adhesion and growth and mineralization. *Carbohydr. Polym*. 129:135–142. https://doi.org/10.1016/j.carbpol.2015.04.043

Liswidowati, B. H., M. Karina, W. Syafii, S. Suzuki, T. Umezawa, and M. Shimada. 2001. Isolation of Syringaresinol from *Paraseranthes falcataria* (L.) Nielsen. *Wood Res.: Bull. Wood Res. Inst., Kyoto Univ*. 88:40–41. http://hdl.handle.net/2433/53137. Accessed May 18, 2023.

Liu, F., X. Bai, F. Q. Yang, X. J. Zhang, Y. Hu, P. Li, and J. B. Wan. 2016. Discriminating from species of Curcumae radix (Yujin) by a UHPLC/Q-TOFMS-based metabolomics approach. *Chin. Med*. 11:21.

Lu, J., M. Venäläinen, R. Julkunen-Tiitto, and A. M. Harju. 2015. Stilbene impregnation retards brown-rot decay of Scots pine sapwood. *Holzforschung* 70:261–266.

Macheix, J. J., A. Fleuriet, and C. Ay-Allemand. 2005. Les composés phénoliques des végétaux: Un exemple de métabolites secondaires d'importance économique. Presses Polytechniques et Universitaires Romandes, Lausanne. Collection Biologie Series. 192 pp.

Malca-Garcia, G. R., D. Zagal, J. Graham, D. Nikolić, J. B. Friesen, D. C. Lankin, S.-N. Chen, and G. F. Pauli. 2019. Dynamics of the isoflavone metabolome of traditional preparations of Trifolium pratense L. *J. Ethnopharmacol*. 238: 111865. https://doi.org/10.1016/j.jep.2019.111865

Mann, J. 1998. Natural Products: Their Chemistry and Biological Significance. Longman Scientific & Technical, New York.

Maranhão, C. A., I. O. Pinheiro, L. B. D. A. Santana, L. S. Oliveira, M. S. Nascimento, and L. W. Bieber. 2013. Antitermitic and antioxidant activities of heartwood extracts and main flavonoids of *Hymenaea stigonocarpa* Mart. *Int. Biodeterior. Biodegrad*. 79:9–13.

Marei, G. I. K., M. A. Abdel Rasoul, and S. A. M. Abdelgaleil. 2012. Comparative antifungal activities and biochemical effects of monoterpenes on plant pathogenic fungi. *Pestic. Biochem. Physiol*. 103:56–61.

Martins, S., S. I. Mussato, G. Martinez-Avila, J. Montanez-Saenz, C. N. Aguilar, and J. A. Teixeira. 2011. Bioactive phenolic compounds: Production and extraction by solid-state fermentation. A review. *Biotech. Adv*. 29:365–373.

Mbakidi-Ngouaby, H., E. Pinault, V. Gloaguen, G. Costa, V. Sol, M. Millot, and L. Mambu. 2018. Profiling and seasonal variation of chemical constituents from *Pseudotsuga menziesii* wood. *Ind. Crops Prod*. 117 (March):34–49. https://doi.org/10.1016/j.indcrop.2018.02.069

Mbambo, B., B. Odhav, and V. Mohanlall. 2012. Antifungal activity of stigmasterol, sitosterol and ergosterol from *Bulbine natalensis* Baker (Asphodelaceae). *J. Med. Plants Res*. 6:5135–5141.

Mburu, F., S. Dumarçay, and P. Gérardin. 2007. Evidence of fungicidal and termicidal properties of *Prunus africana* heartwood extractives. *Holzforschung* 61:323–325.

Mehta, H. D., S. V. Mangrulkar, and A. J. Chourasia. 2015. A review on *Griffonia simplicifolia*—A natural anti-depressant. *Int. J. Phytopharm*. 6(2):76–79.

Meullemiestre, A. 2014. Valorisation des déchets de la filière ''bois'' en deux étapes: Isolation des molécules extractibles puis fabrication de charbon actif: Cas du pin maritime. Thesis, Génie des Procédés, Université de La Rochelle, Français. https://inria.hal.science/tel-01174996/. Accessed May 18, 2023.

Meullemiestre, A., E. Petitcolas, Z. Maache-Rezzoug, F. Chemat, and S. A. Rezzoug. 2016. Impact of ultrasound on solid-liquid extraction of phenolic compounds from maritime pine sawdust waste. *Kinet. Optim. Large Scale Exp. Ultrason. Sonochem*. 28:230–239. https://doi.org/10.1016/j.ultsonch.2015.07.022

Mijnsbrugge, K. V., H. Meyermans, M. Van Montagu, G. Bauw, and W. Boerjan. 2000. Wood formation in poplar: identification, characterization, and seasonal variation of xylem proteins. *Planta* 210:589–598.

Miller, N. J., C. Rice-Evans, M. J. Davies, V. Gopinathan, and A. Milner. 1993. A novel method for measuring antioxidant capacity and its application to monitoring the antioxidant status in premature neonates. *Clin. Sci*. 84:407–412.

Minato, K. and K. Sakai. 1997. The vibrational properties of wood impregnated with extractives of some species of Leguminosae. *Mokuzai Gakkaishi* 43(12):1035–1037.

Mitra, S. 2003. Sample Preparation Techniques in Analytical Chemistry. *In:* Chemical Analysis: A Series of Monographs on Analytical Chemistry and its Applications, J. D. Winefordner (Ed.), volume 162. Wiley-Interscience (John Wiley & Sons, Inc.), Hoboken, New Jersey. https://onlinelibrary.wiley.com/doi/pdf/10.1002/0471457817.fmatter. Accessed May 18, 2023.

Mosedale, J. R., F. Feuillat, R. Baumes, J. L. Dupouey, and J. L. Puech. 1998. Variability of wood extractives among *Quercus robur* and *Quercus petraea* trees from mixed stands and their relation to wood anatomy and leaf morphology. *Can. J. Forest Res*. 28(7):994–1006.

Mounguengui, S., J. B. Saha Tchinda, M. Kor Ndikontar, S. Dumarçay, C. Attéké, D. Perrin, E. Gelhaye, and P. Gérardin. 2016. Total phenolic and lignin contents, phytochemical screening, antioxidant and fungal inhibition properties of the heartwood extractives of ten Congo Basin tree species. *Ann. Forest Sci*. 73:287–296. https://doi.org/10.1007/s13595-015-0514-5

Mounguengui, W. S. 2008. Caractérisation HPLC de marqueurs permettant de prévoir l'évolution de certaines propriétés macroscopiques du bois lors de différents processus de dégradation. Thèse. UMR 1093 INRA/ENGREF/UHP, Laboratoire d'Etudes et de Recherches sur le Matériau Bois Faculté des Sciences et Techniques, Université Henri Pointcaré-Nancy 1, Nancy, France. http://docnum.univ-lorraine.fr/public/SCD_T_2008_0032_MOUNGUENGUI.pdf. Accessed May 19, 2023.

Moure, A., J. M. Cruz, D. Franco, J. M. Dominguez, and J. Sineiro. 2001. Natural antioxydants from residual sources. *Food Chem*. 72:145–171.

Mueller-Harvey, I., R. D. Hartley, J. D. Reed. 1987. Characterisation of phenolic compounds, including flavonoids and tannins, of ten Ethiopian browse species by high performance liquid chromatography. *J. Sci. Food Agric*. 39:1–14.

N'Guessan, K., B. Kadja, G. N. Zirihi, D. Traoré, and L. Aké-assi. 2009. Screening phytochimique de quelques plantes médicinales ivoiriennes. *Sci. Nat*. 6:1–15.

Nacoulma-Ouédraogo, O. 1996. Plantes médicinales et pratiques médicales traditionnelles au Burkina Faso: Cas du Plateau central. Thèse de Doctorat ès Sciences Naturelles, Université de Ouagadougou, Burkina-Faso. 605 pp.

Naima, R., M. Oumam, H. Hannache, A. Sesbou, B. Charrier, A. Pizzi, and F. Charrier-El Bouhtoury. 2015. Comparison of the impact of different extraction methods on polyphenols yields and tannins extracted from Moroccan *Acacia mollissima* barks. *Ind. Crops Prod*. 70:245–252.

Niamké, B. F., N. Amusant, J. P. Charpentier, G. Chaix, Y. Baissac, N. Boutahar, A. A. Adima, S. Kati-Coulibaly, and C. Jay-Allemand. 2011. Relationships between biochemical attributes (non structural carbohydrates and phenolics) and natural durability against fungi in dry teak wood (*Tectona grandis* L. f.). *Ann. Forest Sci*. 68:201–211.

Niamké, F. B., N. Amusant, D. Stien, G. Chaix, Y. Lozano, A. A. Kadio, N. Lemenager, D. Goh, A. A. Adima, S. Kati-Coulibaly, C. Jay-Allemand. 2012. 4′-5′-Dihydroxy-epiisocatalponol, a new naphthoquinone from Tectona grandis L.f. heartwood and fungicidal activity. *Int. Biodeterior. Biodegrad*. 74:93–98.

Nogales-Bueno, J., B. Baca-Bocanegra, A. Rooney, J. M. Hernández-Hierro, H. J. Byrne, and F. J. Heredia. 2017. Study of phenolic extractability in grape seeds by means of ATR-FTIR and Raman spectroscopy. *Food Chem*. 232:602–609.

Norin, T. 1981. Wood extractives—Their biological significance and their importance for the protection of wood and forest trees. Presented at the Ekman-Days International Symposium of Wood and Pulping Chemistry, Stockholm, June 9–12, 1981. pp. VI:1–3.

Nuutinen T. 2018. Medicinal properties of terpenes found in *Cannabis sativa* and *Humulus lupulus*. *Eur. J. Med. Chem*. 157:198–228. https://doi.org/10.1016/j.ejmech.2018.07.076

Nzokou, P., K. Wehner, and D. P. Kamdem. 2005. Natural durability of eight tropical hardwoods from Cameroon. *J. Trop. Forest Sci*. 17(3):416–427.

Ohmura, W., S. Doi, and M. Aoyama. 2000. Antifeedant activity of flavonoids and related compounds against the subterranean termite *Coptotermes formosanus* Shiraki. *J. Wood Sci*. 46:149–153.

Oliveira, L. S., A. L. B. D. Santana, C. A. Maranhão, R. C. M. Miranda, V. L. A. Galvão de Lima, S. I. Silva da, M. S. Nascimento, and L. Bieber. 2010. Natural resistance of five woods to Phanerochaete chrysosporium degradation. *Int. Biodeterior*. *Biodegrad*. 64:711–715.

Onuorah, E. O. 2000. The wood preservative potentials of heartwood extracts of *Milicia excelsa* and *Erythrophleum suaveolens*. *Bioresour. Technol*. 75(2):171–173. https://doi.org/10.1016/S0960-8524(99)00165-0

Pandey, K. K., and A. J. Pitman. 2004. Examen de la teneur en lignine d'un bois résineux et d'un bois dur décomposés par un champignon de la pourriture brune par la méthode au bromure d'acétyle et la spectroscopie infrarouge à transformée de Fourier. *J. Polym. Sci., Part A: Polym. Chem*. 42(10):2340–2346.

Parage, C. 2013. Génomique fonctionnelle de la biosynthèse des stilbènes chez la vigne (*Vitis vinifera*). Sciences Agricoles. Thèse de doctorat. Université de Strasbourg, France. 201 pp.

Patra, J. K., G. Das, S. Lee, S. S. Kang, and H. S. Shin. 2018. Selected commercial plants: A review of extraction and isolation of bioactive compounds and their pharmacological market value. *Trends Food Sci. Technol*. 82 (April):89–109. https://doi.org/10.1016/j.tifs.2018.10.001

Pelletier, S. W. (Ed.). 1983. Alkaloids: Chemical and Biological Perspectives. Vol. 1. John Wiley & Sons, New York. 398 pp.

Pérez-Bonilla, M., S. Salido, T. A. Van deek, P. J. Linares-Palomino, J. Altarejos, M. Nogueras, and A. Sanchez. 2006. Isolation and identification of radical scavengers in olive tree (*Olea europaea*) wood. *J. Chromatogr. A* 1112(1–2):311–318.

Pietta, P. G. 2000. Flavonoids as antioxidants. *J. Nat. Prod*. 63:1035–1042.

Piispanen, R., S. Willför, P. Saranpaa, and B. Holmbom. 2008. Variation of lignans in Norway spruce (*Picea abies* [L.] Karst.) knotwood: Within-stem variation and the effect of fertilisation at two experimental sites in Finland. *Trees* 22 (3):317–328.

Qa'dan, F., A. Nahrstedt, M. Schmidt, and K. Mansoor. 2010. Polyphenols from *Ginkgo biloba*. *Sci. Pharm*. 78:897–907.

Raicht, R. F., B. I. Cohen, E. P. Fazzini, A. N. Sarwal, and M. Takahashi. 1980. Protective effect of plant sterols against chemically induced colon tumors in rats. *Cancer Res*. (40):403–405.

Rangel, G., H. Chapuis, M. C. Basso, A. Pizzi, C. Delgado-Sánchez, V. Fierro, A. Celzard, and C. Gerardin. 2001. Improving water repellence and friability of tannin-furanic foams by oilgrafted flavonoid tannins. *BioResources* 11, no 3:7754–7768.

Direction de la Production et de l'Industrie Forestière (DPIF), Cote d'Ivoire. 2017. Rapport d'observation independante externe sur le périmètre d'exploitation forestière 20 500 Côte d'Ivoire.

Raven, P. H., R. F. Evert, and S. E. Eichhorn. 2000. Biologie Végétale. Editions De Boeck Université, Paris. 944 pp.

Rodrigues, A. M. S., D. Stien, V. Eparvier, L. S. Espindola, J. Beauchêne, N. Amusant, N. Leménager, C. Baudassé, and L. Raguin. 2012. The wood preservative potential of longlasting Amazonian wood extracts. *Int. Biodeterior*. *Biodegrad*. 75:146–149. https://doi.org/10.1016/j.ibiod.2012.03.014

Roesyadi, A. 1987. Valorisation de la sciure de bois de peuplier par autohydrolyse, hydrolyse acide, et hydrogenolyse sur des catalyseurs à base de ruthenium imprégné sur du charbon actif. Etude d'un réacteur triphasé d'hydrogenolyse de type verlimob à base d'un venturi à émulsion. Application du réacteur à l'hydrogenolyse de solutions aqueuses de glucose. Thèse de Doctorat présentée à l'Université Technologique de Compiègne, France.

Rakotoniaina, A. I., S. S. Rafaramalala, M. K. Ranaivosoa, A. R. Mampionona, and A. Rasamindrakotroka. 2018. Prévalence de l'hyperglycémie à jeun au sein du CHU Mitsinjo Betanimena, Tuléar, Madagascar. *Med. des Mal. Metab*. 12(8):702–704.

Roussel-Bousta, C. 2000. Utilisation de biomolécules à activité biocide élevée comme agents de préservation du bois. Applications à la rosine du tall-oil et aux tropolones naturelles. Thèse de Doctorat d' l'Université Henri Poincaré, Nancy 1, France.

Royer, M. 2008. Les molécules responsables de la stabilité des bois: Cas des bois tropicaux de Guyane Française. Unité Mixte de Recherche Ecologie des forêts de Guyane, Université des Antilles et de la Guyane, Cayenne. 242 pp.

Royer, M., D. Stien, J. Beauchêne, G. T. Herbette, J. P. McLean, A. Thibaut, and B. Thibaut. 2010. Extractives of the tropical wood wallaba (*Eperua falcata* Aubl.) as natural anti-swelling agents. *Holzforschung* 64(2):211–215.

Rustan, A. C. and C. A. Drevon. 2005. Fatty Acids: Structures and Properties. John Wiley & Sons, Ltd., Chichester, West Sussex, England. https://doi.org/10.1038/npg.els.0003894

Saha Tchinda, J-B. 2015. Caractérisation et valorisation des substances extractibles de cinq essences camerounaises majeures de l'industrie du bois : Ayous, Moabi, Movingui, Padouk et Tali. Université de Lorraine, Français. https://hal.univ-lorraine.fr/tel-01751831/file/DDOC_T_2015_0113_SAHA_TCHINDA.pdf. Accessed May 18, 2023.

Saha Tchinda, J-B., K. M. Ndikontar, A. D. Fouda Belinga, S. Mounguengui, J. M. Njankouo, S. Durmaçay, and P. Gérardin. 2018. Inhibition of fungi with wood extractives and natural durability of five Cameroonian wood species. *Ind. Crops Prod*. 123:183–191. https://doi.org/10.1016/j.indcrop.2018.06.078

Sánchez, C., F. Santiago-Medina, V. Fierro, A. Pizzi, and A. Celzard. 2018. Optimization of ''green'' tannin-furanic foams for thermal insulation by experimental design. *Mater. Des*. 139:7–15.

Saniewska, A. and A. Jarecka. 2008. The inhibitory effect of tropolone and hinokitiol on the growth and development of *Fusarium oxysporum* f. sp. *tulipae*. *Phytopath. Polon*. 50:33–41.

Santana, A. L. B. D., C. A. Maranhão, J. C. Santos, F. M. Cunha, G. M. Conceição, L. W. Bieber, and M. S. Nascimento. 2010. Antitermitic activity of extractives from three Brazilian hardwoods against *Nasutitermes corniger*. *Int. Biodeterior*. *Biodegrad*. 64:7–12.

Santos, K. A., J. E. Gonçalves, L. Cardozo-Filho, and E. A. da Silva. 2019. Pressurized liquid and ultrasound-assisted extraction of α-bisabolol from candeia (*Eremanthus erythropappus*) wood. *Ind. Crops Prod*. 130 (January):428–435. https://doi.org/ 10.1016/j.indcrop.2019.01.013

Schultz, T. P., W. B. Harms, T. H. Fisher, K. D. Mcmurtrey, J. Minn, and D. D. Nicholas. 1995.Durability of angiosperm heartwood: The importance of extractives. *Holzforschung* 49(1):29–34.

Schultz, T. P. and J. J. Nicholos. 2000. Naturally durable heartwood: Evidence for a proposed dual defensive function of the extractives. *Phytochemistry* 54:47–52.

Sghaier, M. B., I. Skandrani, N. Nasr, M. G. D. Franca, L. Chekir-Ghedira, and K. Ghedira. 2011. Flavonoids and sesquiterpenes from Tecurium ramosissimum promote antiproliferation of human cancer cells and enhance antioxidant activity: a structure-activity relationship study. *Environ Toxicol Pharmacol*. 32(3): 336–348. https://doi.org/10.1016/j.etap.2011.07.003

Sharma, S. H., S. Thulasingam, and S. Nagarajan. 2017. Terpenoids as anti-colon cancer agents—A comprehensive review on its mechanistic perspectives. *Eur. J. Pharmacol*. 795:169–178.

Selvamuthukumaran, M., and J. Shi. 2017. Progrès récents dans l'extraction des antioxydants des industries de transformation des sous-produits végétaux. *Qualité et sécurité des aliments* 1(1):61–81.

Sirmah, P., S. Dumarçay, and P. Gérardin. 2009a. Effect of unusual amount of (-)-mesquitol of from the heartwood of *Prosopis juliflora*. *Nat. Prod. Res*. 23:183–189.

Sirmah, P., K. Iaych, B. Poaty, S. Dumarçay, and P. Gerardin. 2009b. Effect of extractives on durability of *Prosopis juliflora* heartwood. *In:* Conference: 09-05-24/28: IRG / 40th Annual Meeting of International Research Group on Wood Protection, Beijing. Volume IRG/WP 09-30518.

Smeds, A. I., I. Ceskova, P. C. Eklund, and S. M. Wilför. 2012. Identification of new lignans in Norway spruce knotwood extracts. *Holzforschung* 66:553–567.

Smith-Kielland, I., J. M. Dornish, K. E. Malterud, G. Hvistendahl, C. Romming, O. C. Bockman, P. Kolsaker, Y. Stenstrom, and A. Nordal. 1996. Cytotoxic triterpenoides from the leaves of *Euphorbia pulcherrima*. *Planta Med*. 62:322–325.

Souleymane, F. 2005. Exploration biochimique sur le pouvoir immunogène de trois plantes en Côte d'Ivoire *Alstonia boonei*, *Mitragyna ciliata, Terminalia catappa*. Thèse de Doctorat, Université de Bamako, Mali. 102 pp.

Stevanovic, T. 2011. Potentiel de Développement Lié aux Extractibles Forestiers du Quebec. Année Internationale des Forêts-Forêts 2011. Université de Laval, Quebec, Canada. 53 pp.

Stevanovic, T., and D. Perrin. 2009. Chimie du Bois. Presses Polytechniques et Universitaires Romandes, Nancy, France. 241 pp.

Taga, M. S., E. E. Miller, and D. E. Pratt. 1984. Chia seeds as a natural lipid antioxydants. *J. Am. Oil Chem. Soc*. 61:928–931.

Taubert, D. 2003. Reaction rate constants of superoxide scavenging by plant antioxidants. *Free Radic*. *Biol. Med*. 35:1599–1607.

Taylor, A. M., B. L. Gartner, and J. J. Morrell. 2006. Effects of heartwood extractive fractions of *Thuja plicata* and *Chamaecyparis nootkatensison* wood degradation by termites or fungi. *J. Wood Sci*. 52:147–153.

Thévenon, M. F., C. Roussel, and J. P. Haluk. 2001. Possible durability transfer from durable to non-durable wood species. The case study of teak wood. The International Research Group on Wood Preservation, 32nd Annual Meeting, Nara, Japan, May 20-251. IRG SECRETARIAT SE-100 44, Doc n° IRG/WP 01-10392, Stockholm. 6 pp.

Tiwari, B. K. 2015. Ultrasons : Une technologie d'extraction propre et verte. *Tendances TrAC en chimie analytique* 71:100–109.

Tongnuanchan, P. and S. Benjakul. 2014. Essential oils: Extraction, bioactivities, and their uses for food preservation. *J. Food Sci*. 79 (7):1231–1249. https://doi.org/ 10.1111/1750-3841.12492

Trematerra, P. and A. Sciarretta. 2002. Activity of chilli, *Capsicum annuum* L. var. *acuminatum,* on stored product insects *Oryzaephilus surinamensis* (L.), Sitophilusoryzae (L.) and *Tribolium castaneum* (Herbst). *In:* Proceedings of the meeting, C. Adler, S. Navarro, M. Schöller, and L. Stengard-Hansen (Eds.), September 3–5, 2001, Lisbon, Portugal. International Organization for Biological and Integrated Control of Noxious Animals and Plants, West Palearctic Regional Section (IOBC/WPRS), Bulletin 25 (3):177–182.

Turley, D. B., Q. Chaudhry, R. W. Watkins, J. H. Clark, and F. E. I. Deswarte. 2006. Chemical products from temperate forest tree species—Developing strategies for exploitation. *Ind. Crops Prod*. 24:238–243.

Umezawa, T. 2003. Diversity in lignan biosynthesis. *Phytochem. Rev*. 2:371–390.

Välimaa, A. L., U. Honkalampi-Hämäläinen, S. Pietarinen, S. Willför, B. Holmbom, and A. von Wright. 2007. Antimicrobial and cytotoxic knotwood extracts and related pure compounds and their effects on food-associated microorganisms. *Int. J. Food Microbiol*. 115:235–243.

Venalainen, M., M. Anni, H. P. Saranpa, P. Kainulainen, M. Tiitta, and P. Velling. 2004. The concentration of phenolics in brown-rot decay resistant and susceptible Scots pine heartwood. *Wood Sci. Techno*. 38:109–118.

Venkata, R. B., S. La, S. M. Pardha, and B. Narashimha. 2012. Antibactérial, antioxidant activity and GC-MS analysis of *Eupatotium odoratum*. *Asian J. Pharm. Clin. Res*. 2:99–106.

Wan Mohd, S. N. H. W., M. A. Nafiah, M. H. Jauri, and S. Khamis. 2021. Chemical constituents and acetylcholinesterase inhibitory activity of Beilschmiedia insignis Gamble. *Bull. Chem. Soc. Ethiop*. 35(3):685–691.

Wang, Y., K. W. Lee, F. L. Chan, S. Chen, and L. K. Leung. 2006. The red wine polyphenol resveratrol displays bi-level inhibition on aromatase in breast cancer cells. *Toxicol. Sci*. 92:71–77.

Wang, Y., Y. Zu, J. Long, Y. Fu, S. Li, D. Zhang, J. Li, M. Wink, and T. Efferth. 2011. Enzymatic water extraction of taxifolin from wood sawdust of *Larix gmelini* (Rupr.) Rupr. and evaluation of its antioxidant activity. *Food Chem*. 126:1178–1185. https://doi.org/10.1016/j.foodchem.2010.11.155

Wang, L., and C. L. Weller. 2006. Recent advances in extraction of nutraceuticals from plants. *Trends Food Sci. Technol*. 17(6):300–312.

Wen, P., T. G. Hu, R. J. Linhardt, S. T. Liao, H. Wu, and Y. X. Zou. 2019. Mulberry: A review of bioactive compounds and advanced processing technology. *Trends Food Sci*. *Technol*. 83 (May 2018):138–158. https://doi.org/10.1016/j.tifs.2018.11.017

Willför, S. M., J. Hemming, M. Reunanen, C. Eckerman, and B. Holmbom. 2003. Lignans and lipophilic extractives in Norway spruce knots and stemwood. *Holzforschung* 57:27–36.

Willför, S. M., A. I. Smeds, and B. R. Holmbom. 2006. Chromatographic analysis of lignans. *J. Chromatogr*. 1112:64–77.

Woyengo, T. A., V. R. Ramprasath, and P. J. H. Jones. 2009. Anticancer effects of phytosterols. *Eur. J. Clin. Nutr*. 63:813–820.

Wu, J. F., X. F. Zhuang, H. M. Yuan, Q. Li, W. Wang, J. Q. Li, and J. G. Lin. 2020. Antifungal ability and decay resistance of *Fokienia hodginsii* heartwood extract and its inhibitory effect on *Gloeophyllum trabeum*. *BioResources* 15(2):2784–2799. https://doi.org/10.15376/biores.15.2.2784–2799

Yinyang, J., E. M. Mpondo, M. Tchatat, R. C. Ndjib, P. M. Ottou, and S. D. Dibong. 2014. Les plantes à alcaloïdes utilisées par les populations de la ville de Douala (Cameroun). *J. Appl. Biosci*. 78:6600–6619. https://doi.org//10.4314/jab.v78i0.7

Zeng, X. L., G. M. Fu, K. Tian, J. X. Sun, H. B. Xiong, X. Z. Huang, and Z. Y. Jiang. 2014. Acutissimanide, a new lignan with antioxidant activity isolated from the bark of *Quercus acutissima* Carruth. *Nat. Prod. Res*. 1:1–7.

Zhang, B., J. Cai, C. Q. Duan, M. J. Reeves, and F. He. 2015. A review of polyphenolics in oak woods. *Int. J. Mol. Sci*. 16:6978–7014.

Zhou, W., Y. He, X. Lei, L. Liao, T. Fu, Y. Yuan, X. Huang, L. Zou, Y. Liu, R. Ruan, and J. Li. 2020. Chemical composition and evaluation of antioxidant activities, antimicrobial, and anti-melanogenesis effect of the essential oils extracted from *Dalbergia pinnata* (Lour.) Prain. *J. Ethnopharmacol.* 254 (November 2019): 11273. https://doi.org/10.1016/j.jep.2020.112731

Zulfiqar, S., S. Ahmed, M. Sufyan, M. Arshad, A. Nawaz, and B. Hassan. 2020. Termiticide activities of wood extractives of *Ziziphus mauritiana* (Rhamnaceae) against subterranean termites under field conditions. *Rev. Bras. De*. *Entomol*. 64(1):1–6. https://doi.org/10.1590/1806-9665-RBENT-2019-98

Zwingelstein, M., M. Draye, J. L. Besombes, C. Piot, and G. Chatel. 2020. Viticultural wood waste as a source of polyphenols of interest: Opportunities and perspectives through conventional and emerging extraction methods. *Waste Manag*. 102:782–794. https://doi.org/10.1016/j.wasman.2019.11.034