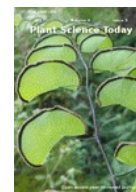




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Mini Review

Distribution of alkaloids in woody plants

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Abstract

Alkaloids are nitrogen-containing compounds found in plants. Most are highly valued for their role in wide array of ailments such as anti-malarial, anti-cancerous, analgesics, and many more. In lights of tremendous interest in recent years on the chemistry and pharmacological properties of alkaloids, comprehensive data have been collected. Forest industries have recently started to develop sustainable ways to increase the value of its residues including the extraction and commercialization of high-valued plant natural compounds such as alkaloids. This review presents the distribution of alkaloids among woody plants (trees and shrubs).

Keywords

Alkaloid; plant secondary metabolism; woody plant; natural products; trees; shrubs; specialized metabolites

Abbreviations

PNC, plant natural compounds; DMT, N, N-dimethyltryptamine

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Introduction

Morphine, cocaine, quinine, nicotine, caffeine and strychnine are all high-value plant natural compounds (PNC) derived from the specialized (*aka* secondary) metabolism. These alkaloids are known for their biological activity including analgesic, antimicrobial, stimulant, anti-cancer and even poison depending of the dose used. In 1819, W. Meissner uses the term alkaloid (alkaline compound) to identify plant substances of basic character containing one nitrogen atom (1). To date, more than 21,000 alkaloids have

been reported and are classified according to several criteria including their chemical structures, their biosynthetic origins and their biological and ecological activities (2). Most alkaloids characterized to date originate from herbaceous plants and information on alkaloids from woody trees or shrubs are scarce.

Alkaloids are nitrogenous heterocyclic organic molecules derived from amino acids and are mainly found in plants and fungi (3). Although alkaloids are often present in small quantities in plants, they possess potent biological activities at low

doses. It is proposed that the physiological role of alkaloids is involved in the defense against pathogens and herbivores. Several biological properties of alkaloids including antimicrobial, cytotoxic, analgesic and poison activity seem to support this role. Once purified, alkaloids often have acute toxicity but at low doses, they can serve as medicines. To date, many alkaloids and alkaloid-producing plants are used for the treatment of various ailments. Plant specialized metabolites such as alkaloids have limited distribution compared to primary metabolites because all secondary biogenetic pathways are not operational in all species or tissues and can terminate at different stages. These metabolites can be characteristic of a family, a genus, species, or even cultivars of the same species. They form a basis of chemo-taxonomy because they reflect in part the enzyme systems that produced them, so the genetic makeup of a tree. The alkaloid profile of a plant, or a plant extract, is often presented as a complex mixture which contains some major alkaloids and few minor ones (present at lower concentrations). For example, the alkaloid profiles of opium poppy extracts differ among various cultivars (4).

2. Woody plants

Woody plants such as trees and shrubs provide numerous environmental, social and economic benefits for people. In many countries, the forest industry is of major ecological, economic and social importance. As a response to criticism of some forestry practices, sustainable forestry was developed and has become commonplace in many areas. Thus, forest industry continuously develops strategies for better exploitation of the forest resources and new sectors in a sustainable manner. One such sector includes the extraction of high-valued PNC from forest residues. The emergence of this industry is based on three elements: 1) the need for new bioactive natural compounds for the nutraceutical, cosmetic, pharmaceutical and food industry, 2) the search for added alternatives for residues in terms of energy and raw materials, and 3) a way of recovering forest biomass to gain greater profitability. Some of forest PNC identified possess several physicochemical, biological and therapeutic activities. For example, residual barks are rich in polyphenols which have recognized properties as antioxidants, anticancer agents, antibiotics, or anti-inflammatories. Thus, the extraction of forest residues such as bark, provides a wide range of products and according to their properties, multiple applications can be envisaged. For example, terpene monomers (pinene, limonene) can enter the formulation of perfumes, phenolic compounds (tannins) are good replacements for phenol in resins for wood-based materials, and simple phenols (stilbenes, lignans, flavonoids) can be included in the formulation of

products in nutrition of animal or human health. To date, few comprehensive phytochemical studies have focused on residual tissues of woody plant species and even less reported the presence of alkaloids. Consequently, in the world of commercial wood extracts, alkaloids are often forgotten due to lack of information on the presence of these compounds in the studied species and / or their low accumulation in trees. Therefore, the current review reports the alkaloids detected in woody plants.

3. Alkaloids in woody plants

In contrast to the extensive literature on PNC of the terpenoid and phenolic groups in woody plants (trees and shrubs), information on the alkaloid group is rare, sparse and limited. Table 1 presents a summary of the literature on the alkaloids present in woody plants. Alkaloids are reported and classified according to their chemical structure.

One important alkaloid from trees is taxol (paclitaxel®), a successful anti-cancer agent from *Taxus brevifolia* (5). It was first isolated and characterized as part of the National Cancer Institute screening program (6). Since, several other compounds including tree alkaloids, have been identified and characterized as anti-cancer agents including camptothecine, rohitukine, harringtonine, acronycine and ellipticine (Table 1) (5).

Purine alkaloids, also called xanthines, includes the well-known PNCs caffeine, theobromine and theophylline (7). The coffee plant (*Coffea arabica*), a shrub of the Rubiaceae family which is grown for its coffee beans, produced caffeine and other purine alkaloids (Table 1) (7). The cacao tree (*Theobroma cacao*) is a small tree in the Sterculiaceae family producing theobromine in its beans from which cocoa is produced (8). The kola tree (*Cola acuminata*), from the same family as cocoa, produces kola nut, a fruit containing purine alkaloids such as caffeine, kolatine and kolateine (7, 9). Purine alkaloids also exist in several non-woody plants such as guarana, mate and tea. Purine alkaloid allows the plant to protect itself from attack by insects and other herbivores.

In addition to purine alkaloids, the Rubiaceae family includes the quinine tree (*Cinchona pubescens*) sought for its bark with antimalarial activity. It produces quinoline alkaloids such as quinine, quinidine, cinchonine (3) Lemon aspen (*Acronychia acidula*) and several other species of *Acronychia* produce quinoline (acridone) alkaloids such acronycine, melicopine, melicopidine and acronycidine (Table 1) (10). From the same plant family, several species of *Sarcomelicope* also produce acronycine and other quinoline alkaloids (11).

Coca bush (*Erythroxylum Coca*) is a tropical shrub from South America producing the tropane

Table 1: List of alkaloids reported in several families of woody plant such as trees and shrubs.

Alkaloid group	Plant family	Example of species	Example of alkaloid	Reference
Taxane	Taxaceae	<i>Taxus brevifolia</i>	taxol (paclitaxel)	(6, 44)
Chromone	Meliaceae	<i>Amoora rohituka</i>	rohitukine	(45)
Cephalotaxine	Cephalotaxaceae	<i>Cephalotaxus harringtonia</i>	harringtonine	(46)
Purine	Rubiaceae	<i>Coffea arabica</i>	caffeine	(7)
Purine	Sterculiaceae	<i>Theobroma cacao</i>	theobromine	(8)
Purine	Sterculiaceae	<i>Cola acuminata</i>	kolatine	(9)
Quinoline	Rubiaceae	<i>Cinchona pubescens</i>	quinine	(3)
Quinoline	Nyssaceae	<i>Camptotheca acuminata</i>	camptothecine	(47)
Quinoline	Rutaceae	<i>Acronychia acidula</i>	acronycine	(10)
Quinoline	Rutaceae	<i>Sarcomelicope glauca</i>	acronycine	(11)
Tropane	Erythroxylaceae	<i>Erythroxylum coca</i>	cocaine	(12)
Tropane	Moraceae	<i>Morus alba</i>	1-deoxynojirimycin	(13)
Nortropane	Erythroxylaceae	<i>Erythroxylum coca</i>	calystegine	(48)
Phenethylamine	Fabaceae	<i>Acacia rigidula</i>	dimethyltryptamine	(15, 17)
Phenethylamine Indole	Fabaceae	<i>Anadenanthera peregrina</i>	bufotenine harmine	(16)
Indole	Aceraceae	<i>Acer saccharinum</i>	harmine	(18)
Indole	Simaroubaceae	<i>Simarouba glauca</i>	cathin-6-one	(19)
Indole	Rubiaceae	<i>Pausinystalia yohimbe</i>	yohimbine	(3, 23, 24)
Indole	Rubiaceae	<i>Mitragyna speciosa</i>	mitragynine	(21, 22)
Indole	Loganiaceae	<i>Strychnos nux-vomica</i>	strychnine	(3, 25)
Indole	Loganiaceae	<i>Strychnos usambarensis</i> ,	usambarensine	(49)
Indole	Apocynaceae	<i>Ochrosia elliptica</i>	ellipticine	(50)
Pyridine	Lythraceae	<i>Punica granatum</i>	pyridine	(26)
Piperidine	Piperaceae	<i>Piper nigrum</i>	piperine	(28)
Piperidine	Pinaceae	<i>Pinus ponderosa</i>	euphococcine	(29, 30, 32)
Piperidine	Pinaceae	<i>Picea abies</i>	cis-pinidine	(29, 31)
Isoquinoline	Lauraceae	<i>Sassafras albidum</i>	boldine	(33, 35)
Isoquinoline	Lauraceae	<i>Cinnamomum mollissimum</i>	cinnamolaurine	(33, 36)
Isoquinoline	Magnoliaceae	<i>Liriodendron tulipa</i>	N-methylcrotsparine	(37-39)
Isoquinoline	Magnoliaceae	<i>Elmerrillia papuana</i>	elmerrillicine	(40)

alkaloid cocaine (Table 1) (12). Mulberry trees (*Morus alba*) also produce tropane alkaloids such as 1-deoxynojirimycin, also named sugar-mimic-alkaloids because of their structure and their activity against diabetes and obesity (13, 14). Acacia trees from the Fabaceae family are known to produce phenethylamine alkaloids such as *N,N*-dimethyltryptamine (DMT) and other catecholamines (Table 1) (15). DMT is a controlled substance with effects on the nervous system drugs such as 3,4-methylenedioxy-methamphetamine (MDMA) and ecstasy. In addition to synthesizing phenethylamine alkaloids (DMT, bufotenine), the yopo (*Anadenanthera peregrina*), a South American tree that looks like

Acacia, produces indole alkaloids called b-carbolines such as harmine, harmaline, elaeagnine and tryptoline (Table 1) (16, 17). It has been reported that other woody species also accumulate b-carboline alkaloids including the maple tree (*Acer saccharinum*) which produces harmine and elaeagnine and the simarouba tree (*Simarouba glauca*) which synthesizes cathin-6-one and others b-carbolines derivatives (Table 1) (18-20). Alkaloids in the Rutaceae family including canthin-6-one, isolated from bark and leaves of *Zanthoxylum* has cytotoxic and anti-tumor properties (20). Kratom (*Mitragyna speciosa*), a tree found in South East Asia and Africa and used for its wood, belong to the Rubiaceae family same

as *Cinchona* and coffee trees, but produces indole alkaloids such as mitragynine and paynantheine (Table 1) (21, 22). Other indole alkaloids produced by tropical trees include yohimbine from *Pausinystalia yohimbe* and strychnine from *Strychnos nux-vomica* (3, 23-25).

The pomegranate tree (*Punica granatum*) produces pyridine alkaloids (26). Alkaloids were reported to accumulate in white birch but the authors did not specify which ones (27).

Black pepper (*Piper nigrum*) is a woody vine from the Piperaceae family producing berries that give a sought-pepper spice. Piperine with other piperidine alkaloids are responsible for the sensation of heat when eating black pepper. (28) It is interesting to note that in the Pinaceae family (Pine trees), including the genus *Pinus* and *Picea*, also accumulates piperidine alkaloids such as euphococcinine, 2-methyl-6-propyl-1,6-piperidine and *cis*-pinidine (Table 1) (29-32).

Finally, the Lauraceae family includes several species able to produce isoquinoline alkaloids (33, 34). The most frequently detected alkaloids in Lauraceae barks include reticuline, boldine, aporphine, corydine, cinnamolaurine, laurotetanine and lauroitsine (33, 35, 36). These species include the Iroquois bay (*Sassafras albidum*) used in medicine for its antiseptic properties and as a spice in Cajun cooking and the cinnamon tree (*Cinnamomum mollissimum*) providing cinnamon and lumber. Some Magnoliaceae also produces isoquinoline alkaloids including yellow poplar (*Liriodendron tulipa*) accumulating *N*-methylcrotsparine and *Elmerrillia papuana* producing elmerrilicine (37-40).

4. Conclusions

Finding natural, new, safe and economical PNC, especially from abundant and low-value raw materials is a real challenge, especially in an effort to develop "green" product in a sustainable manner (41). Some industries (pharmaceuticals, cosmetics, food additives and nutraceuticals) have increased their efforts to obtain and use commercially bioactive PNCs from diverse plant residues. Forest biomass (mainly trees and shrubs) often contains bioactive PNCs of commercial values. These residues of industrial wood transformation are available in huge quantities, representing an abundant and inexpensive source of bioactive PNC (42, 43). Alkaloids, due to the wide range of biological effects, may represent an interesting avenue for the forest industry to add value to their products and processes.

Author Contribution Statement

IDP designed, structured and wrote the manuscript.

Conflict of Interest

The author declares that she has no conflict of interest.

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