Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2016; 5(2): 247-258
Received: 25-01-2016
Accepted: 27-02-2016

K Sri Rama Murthy
Department of Botany and Biotechnology,
Montessori Mahila Kalasala, Vijayawada - 520 010, Andhra Pradesh, India.

M Chandrasekhara Reddy
Department of Botany and Biotechnology,
Montessori Mahila Kalasala, Vijayawada - 520 010, Andhra Pradesh, India.

S Sandhya Rani
Department of Botany,
Sri Krishnadevaraya University, Anantapur 515 055, Andhra Pradesh India.

T Pullaiah
Department of Botany,
Sri Krishnadevaraya University, Anantapur 515 055, Andhra Pradesh India.

Correspondence
K Sri Rama Murthy
Department of Botany and Biotechnology,
Montessori Mahila Kalasala, Vijayawada - 520 010, Andhra Pradesh, India.

Bioactive principles and biological properties of essential oils of Burseraceae: A review

K Sri Rama Murthy, M Chandrasekhara Reddy, S Sandhya Rani, T Pullaiah

Abstract
Burseraceae is one of the families containing wide range of aromatic plants. In this family resiniferous plants mainly yield essential oils and these oils are mostly extracted from leaves, bark and oleogum resins. In the present review the major constituents of essential oil and their pharmacological properties of nearly sixty species belonging to Burseraceae is given. A number of phytochemicals were isolated from different essential oils of the members of this family. Among those the predominant compounds present in these oils belong to mono and sesquiterpenes. The prominent biological properties exhibited by the essential oils of the members of Burseraceae are antibacterial, anticancer, antifungal, anti-inflammatory, antioxidant, insecticidal and larvicidal.

Keywords: Burseraceae; essential oils, phytochemicals, biological activities

1. Introduction

Burseraceae comprises of approximately 700 species in 19 genera in the tropics and subtropics represented by few taxa in some warm temperate areas [1]. Most of these species are entirely woody, small to large trees but few are shrubby. The trees and shrubs of Burseraceae have in their bark prominent vertical schizogenous resin ducts (containing triterpenoid compounds and ethereal oils) [2] which produce aromatic oils and gum resins that are responsible by many of its medicinal properties [3]. Essential oils are a rich source of bioactive compounds, which have been an increased interest in looking at biological properties of aromatic plants. In nature, essential oils play an important role in protection of phytodiversity as antibacterials, antifungals, antivirals, insecticides and also against herbivores by reducing their appetite for such plants. They attract some insects to favor the dispersion of pollen and seeds, or repel undesirable others. Essential oils are liquid, volatile and rarely colored in nature. Normally they are lipid soluble and soluble in organic solvents with a generally lower density than that of water. Essential oils are odorous principles which are stored in special plant secretary cells, cavities and canals like epidermal cells, glandular trichomes, glands, glandular hairs, oil ducts, resin ducts etc. usually they may occur in buds, flowers, leaves, stems, twigs, seeds, fruits, roots, wood, sap or bark.

Approximately 3000 essential oils are known, of which 300 are commercially important especially in pharmaceutical, agronomic, food, sanitary, cosmetic and perfume industries. Essential oils or some of their components are used in perfumes and make-up products, as food preservers and additives, and as natural remedies in curing various ailments. Aromatherapy is now considered to be another alternative way in healing people and the therapeutic values of aromatic plants lie in their volatile constituents such as monoterpenoids, sesquiterpenoids and phenolic compounds that produce a definite physiological action on the human body [4].

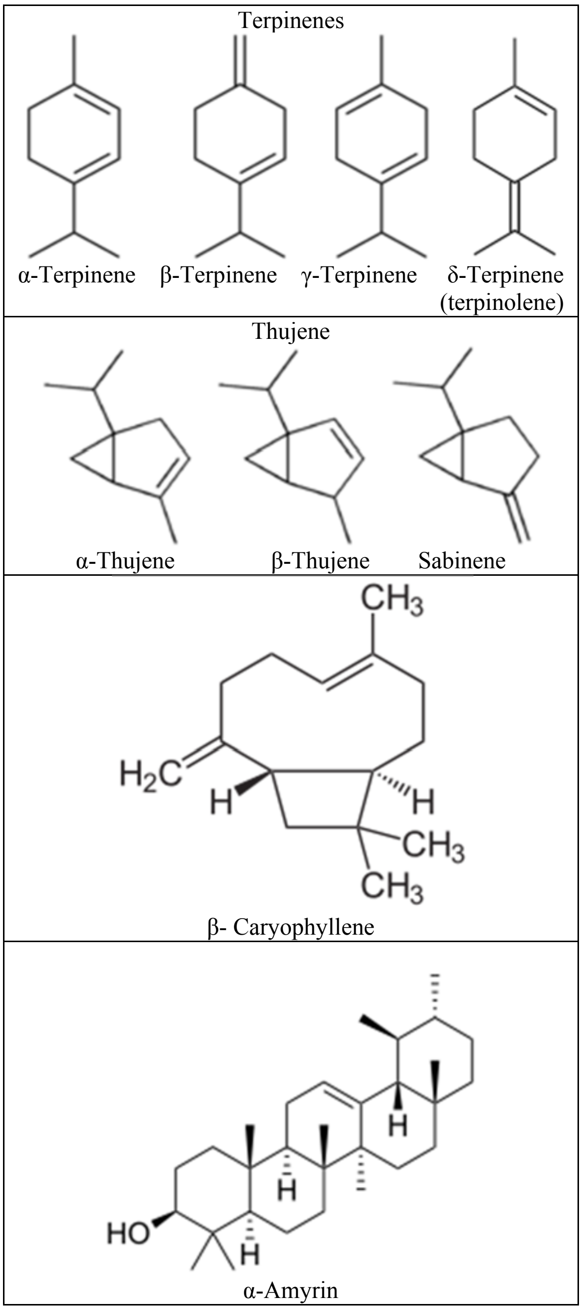
Essential oils are volatile, very complex natural mixtures characterized by a strong odour and are formed by aromatic plants as secondary metabolites, which contain about 20–60 components at quite different concentrations. They are characterized by two or three major components at fairly high concentrations (20-70%) compared to other components present in trace amounts. They are usually extracted either by using steam distillation or hydro-distillation methods. The chemical profile of essential oil differs not only in the number of molecules but also in the stereochemical types of molecules extracted, according to the type of extraction, and the type of extraction is chosen according to the purpose of the use. The extracted oil can vary in quality, quantity and in chemical composition according to climate, soil composition, plant organ, age and vegetative cycle stage [5, 6].

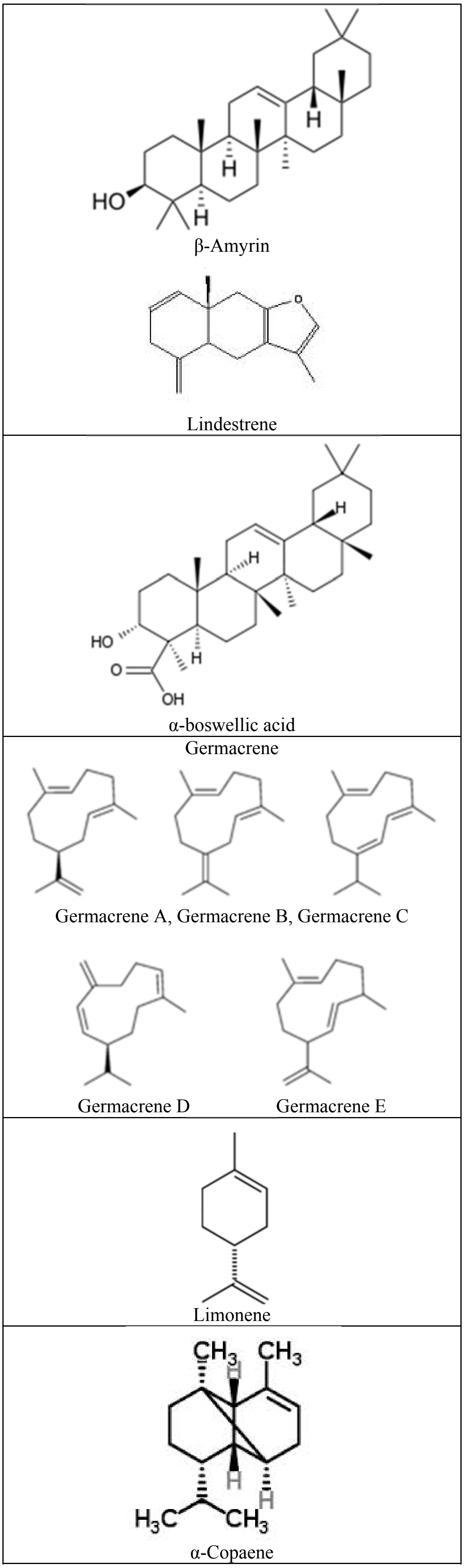
So, in order to obtain essential oils of constant composition, they have to be extracted under the same conditions from the same organ of the plant which has been growing on the same soil, under the same climate and has been picked in the same season [7]. The present review aims to provide the information regarding ethonobotinical uses of Burseraceae, major chemical constituents present in the essential oils and their significant biological applications.

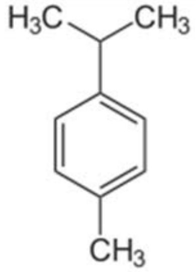
The present review was written based on the literature available regarding the essential oil composition of Burseraceae species. The data presented in this paper was collected from the articles published in repute scientific journals in the area of essential oil research. Few data was also collected from encyclopedias and books.

Review

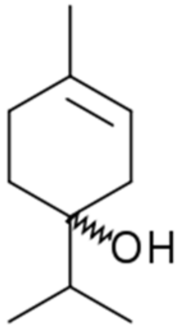
In this review, traditional uses, phytochemistry of essential oil and pharmacological properties of the members of Burseraceae have been reported. The major chemical constituents found in the essential oils of nearly sixty species that belonging to ten genera are given in Table - 1 and Fig - 1.





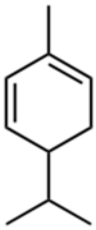


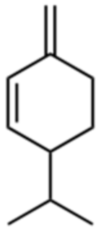
p-cymene



Terpinene-4-ol

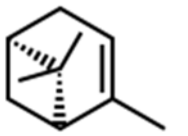
Phellandrene



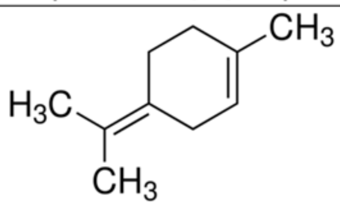


α-Phellandrene β-Phellandrene

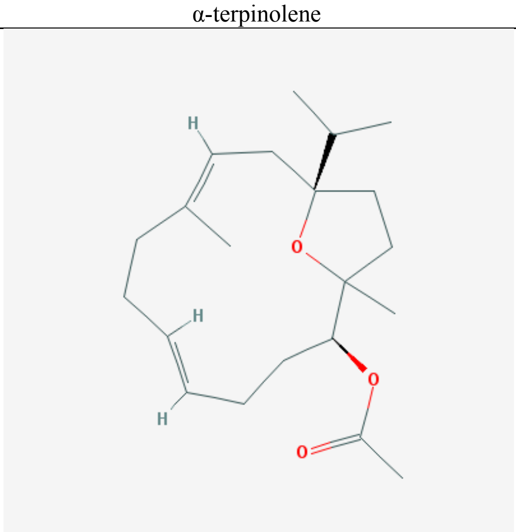
α-Pinene



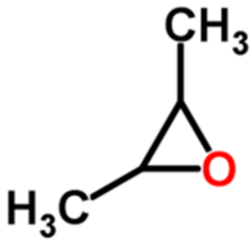
(+)-α-pinene (−)-α-pinene



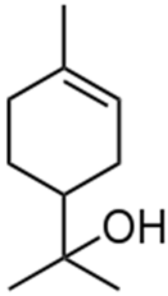
α-terpinolene



Isoincensole acetate



2,3-Epoxybutane



α -terpineol

Traditional uses

The resiniferous trees and shrubs of the family Burseraceae have prominent role in ethnomedicine of the regions where they occur. Such a property has led to the use of species of this family since from ancient times for curing various ailments in humans and animals. Although the family is distributed throughout tropical and subtropical regions of the world, the majority of the ethnomedicinal information available is limited to Asiatic and African genera, such as *Commiphora*, *Canarium*, *Boswellia*, *Bursera*, *Protium*.

The roots and leaves of *Aucoumea klaineana* are used to treat fever, constipation, malaria, diarrhoea and jaundice [8]. *Boswellia serrata* is one of the ancient and most valued herbs in Ayurveda [9]. The gum obtained from this plant is popularly used in Indian Systems of Medicine (Unani, Ayurvedic and Sidha) for the last several centuries in curing various ailments especially rheumatism and skin diseases. Kundur is one of the popular drugs for various ailments such as dysentery, dyspepsia, lung diseases, hemorrhoids, rheumatism, urinary disorders and corneal ulcer in Unani system of medicine. It is also an ingredient in certain compound formulations such as Majoon Kundur, Majoon Murawwah-ul-Arwah, Dawa-ul-Kibrit and Habbe Suzak of Unani medicine used in renal disorders [10]. The traditional applications of frankincense (*Boswellia sacra*) are very diverse ranging from dental disease to skin conditions, respiratory complaints, digestive troubles etc. in the ancient world, from Egypt to China and from India to Rome where Frankincense was grown, every part of the tree such as root, bark, bud, flower and fruit as well as the oleoresin, resin and the essential oil all had their various uses.

A preparation made from the bark of *Canarium indicum* is used for the treatment of chest pains. Bark from the young trees of *Canarium schweinfurthii* is used in tribal medicine for rectal injections. The resin obtained from *C. schweinfurthii* was used for the treatment of various diseases like wounds and microbial infections [11]. *Cedrelopsis grevei* essential oil, obtained from its bark, which known under the name Katrafay oil, is used in Madagascar in folk medicine and in aromatherapy in the areas of the North [12]. Fruits of *Commiphora africana* are used for the treatment of typhoid fever and as a remedy for stomach problems [13]. The powdered bark of *C. africana* is mixed with porridge to cure malaria. The resin also has medicinal uses like disinfection of wounds etc. The fumes of burnt resin are used as an insecticide and as an aphrodisiac [14]. Resins obtained from many *Commiphora* species exhibit diverse therapeutic applications, like wound healing, pain, fracture, mouth ulcer, inflammatory disease, stomach disorders and microbial infection. Recognition of the therapeutic and medicinal value of myrrh (known as guggul in India, the resinous exudates of *Commiphora mukul*) in Ayurvedic system of medicine dates back to 3000 years ago. Guggul is regarded as the most important herb in the authoritative monograph Charaka Samhita for the treatment of obesity, and is used as a hypolipidemic agent to treat lipid disorder etc [15-17].

The dried fruits of Chinese olive (*Canarium album*) are used to treat bacterial and viral infections, inflammation, poisoning and for detoxification. They also used in treatment of angina, dysentery, snake bites, cough-hematemesis, enteritis, diarrhoea, toxicosis from swellfish and alcohol. The bark of *Canarium indicum* has been used for chest pains where as the oil has been patented for treatment of arthritis pain and the oleoresin of the tree is applied as a poultice for ulcerated wounds. *Canarium schweinfurthii* is used by traditional healers as a remedy to cure diabetes mellitus. The plant is also widely used for fever, as stimulant, emollient, in post-partum pain, constipation, malaria, diarrhoea, sexual infections and rheumatism. The decoction prepared from the bark of *Canarium littorale* is used to heal hemorrhoids [18].

Dacryodes edulis is an important medicinal plant in African traditional medicine. This plant is widely used in curing various ailments. The decoction of the bark of this plant is taken orally to treat leprosy. The leaf sap is used as ear drop to cure ear problems. The juice obtained after crushing the leaves is used to treat common skin problems in children like scabies, ringworm, rashes and wounds [19]. The resin obtained from the bark of *Protium* species has been widely used for different purposes by the native tribes in their traditional system of medicine, e.g. as an external agent (cosmetics), to heal wounds, to avoid worsening of broken limbs and teeth, or as emollient, rubefacient and antiseptic. The smoke is inhaled as an analgesic. The root bark is astringent and claimed to have renal clearance and anti-syphilitic properties. Other properties like hemostatic, anti-rheumatic, and for the treatment of gonorrhea, stomach and pulmonary diseases, and in dentistry applications among others are described for different other parts of these species [20].

Phytochemistry

The essential oils obtained from various species of Burseraceae were investigated by several biologists to understand their chemical profile by using GC/FID and GC-MS methods. Hundreds of molecules were isolated from essential oils obtained from various parts of Burseraceae members. In the present review important phytochemical regularities and findings from 1980s and most preferably from 2000 on words are listed (Table-1). With respect to phytochemical aspects of this family, the characteristics as given below deserve our full attention. Terpenoids especially the mono, di, tri, sesqui-terpenoids are the most abundant constituents in the members of this family. The α-pinene, α-phellandrene, *p*-cymene and 1,8-cineole are found to be the major constituents in resin oil of *Aucoumea klaineana* [21]. The essential oil of *Boswellia serrata* predominantly comprised of monoterpenoids, of which α-pinene was the major constituent. Other monoterpenoids such as β-pinene, *cis*-verbenol, *trans*-pinocarveol, borneol, myrcene, verbenone, limonene, thuja-2,4(10)-diene and *p*-cymene were also found along with α-copaene a sesquiterpene [22]. *α*-Thujene, *α*-pinene and terpinen-4-ol were found to be the major components in *Boswellia neglecta*. Whereas limonene in *Boswellia rivae*; trans-verbenol and terpinen-4-ol in *Boswellia pirotta* [23]. *Boswellia carteri* and *Boswellia serrata* oleogum resin oils showed the presence of isoincensole and isoincensole acetate as the major diterpenic compounds. n-octanol and n-octyl acetate, along with the diterpenic compounds were found in *Boswellia papyrifera* resin oil [24].

In *Canarium schweinfurthii* octyl acetate and nerolidol were found to be the major constituents in resin essential oils [25]. Presence of *p*-cymene, limonene and *α*-terpineol were also reported in *C. schweinfurthii* [21]. Monoterpenoids with *β*-pinene, *α*-terpinene, *γ*-terpinene, and terpinen-4-ol as the main components were found in resin essential oil of *Canarium album* [26]. Four chemical patterns were distinguished in bark essential oils of *Cedrelopsis grevei* during chemical investigation [12]. They reported that the first is characterized by eudesmane skeletons, mainly represented by selinenes and eudesmol for the *α* - and γ - isomers, respectively, the second is rich in *α*-pinene and copaborneol, the third is dominated by *α* -copaene and ishwarane, and whereas last by cadinane skeletons (cadinenes, T-muurolol and *α* -cadinol) [12]. Latter they reported majority of compounds present in bark essential oils of C. *grevei* belong to monoterpenes, sesquiterpene and hydrocarbons respectively [27]. In *C. grevei* presence of 64 compounds in leaf essential oils with (*E*)-*β*-farnesene, *δ*-cadinene, *α*-copaene and *β*-elemene as major compounds were reported [28].

In *Commiphora africana* leaf oil presence of α-oxobisabolene and γ-bisabolene was reported [29]. Whereas along with the presence of bisabolones, occurrence of β-sesquiphellandrene was also reported in leaves of *C. africana* [30]. In *Commiphora myrrha* var. *molmol* oil presence of 32 compounds were identified and among those curzerene, furanoeudesma-1,3-diene, β-elemene and 2-0-acetyl-8,12-epoxygermacra-1(10),4,7,11-tetraene, isomer I were found to be the major constituents [31]. The volatile oil of *Commiphora kerstingii* contained (Z)-α-bisabolene, β-bisabolene, linalool and *trans*-α-bergamotene as the major constituents [32]. Occurrence of one toxic compound (dl-Limonene) in *Commiphora molmol* oil was reported by Habeeb et al. [33]. The major constituents in Resin oil of *Commiphora habessinica* were found to be β-elemene, α-selinene, cadina-1,4-diene, germacrene B, α-copaene, t-muurolol, caryophyllene oxide and α-cadinol [34].

A total of 64 components were present in the four essential oils of *Dacryodes edulis* [35]. Among those Myrcene was found to be the dominant constituent of the fruit oil and β-caryophyllene in leaf oils. The stem-bark essential oil contained predominantly terpinen-4-ol and a mixture of α-thujene and α-pinene, whilst α-phellandrene was the major component in the root-bark oil. Where as in fruits and seeds presence of monoterpenes, such as *α*-pinene, *β*-pinene, limonene and *α*-phellandrene as main compounds was identified [36]. Presence of twenty four components in the resin essential oils of *Dacryodes edulis* was reported and among them the main components were found to be sabinene, terpinene-4-ol, α α α α-pinene and *β*-cymene respectively [37, 38].

In some species of *Protium* the resin oil is constituted mainly of monoterpenes and phenylpropanoids such as α-terpinolene, *p*-cymene, *p*-cimen-8-ol, limonene and dillapiole, whereas sesquiterpenes predominate as the volatile constituents in the leaves [39]. Monoterpenes such as *p*-cymene and α- and β-phellandrene were predominant in some species of *Protium* [40]. In *Protium heptaphyllum* the major constituents identified in the leaves were mono and sesquiterpenes such as myrcene and β-caryophyllene whereas oils from resin and fruit contained mainly monoterpenes such as α-pinene, limonene, α-phellandrene, and terpinolene in the resin oil, and α-pinene in the fruit oil [41]. The oil from fruits of *Protium heptaphyllum* was predominant with α-terpinene, whereas oil from leaf contained mainly sesquiterpenes such as 9-epi-caryophyllene, *trans*-isolongifolanone and 14-hydroxi-9-*epi*-caryophyllene respectively [42]. In *Protium icicariba* the resin oil was found to be entirely monoterpenoid and characterized by the predominance of *p*-cymene, followed by α-pinene, α-terpinolene and limonene. Monoterpenes, particularly of the terpinolene-type, predominate in the fruit oil, and germacrene-type sesquiterpenes, followed by α-copaene, γ-elemene and δ-cadinene make the greater part of the leaf oil [43].

The essential oils of the leaves and thin branches of *Protium decandrum*, *Protium pilosum* and *Protium spruceanum*, and of the resins of *Protium altsonii* and *Protium strumosum* were investigated for their chemical composition [44]. The major constituent identified in the oil of *P. decandrum* was α-pinene. The oil of *P. pilosum* was rich in α-pinene, *p*-cymene and α-phellandrene. Whereas Sabinene, was the major constituent present in the oil of *P. spruceanum*. The resin of the species *P. strumosum* and *P. altsonii* showed a totally different composition pattern, consisting of limonene, and *p*-cymene, trans-dihydro-α-terpineol respectively. Similarly oil of *Protium crassipetalum* leaves and branches showed predominance of α-copaene and *trans*-caryophyllene respectively, besides spathulenol was found in the oil of the leaves. The oils of *Protium pilosissimum* were marked by presence of β-sesquiphellandrene in leaves and selin-11-en-4-α-ol in branches. Khusimone was found to be the major constituent in the oil of *P. polybotryum* [45]. The bark oil of *Santiria trimera* contains a high content of monoterpenes, α-pinene being the major component, followed by β-pinene [46] and α-terpineol [47]. Whereas the leaf essential oil was dominated by sesquiterpenes, among which α-humulene and β-caryophyllene were found to be the major components [47].

Table 1: Major compounds in essential oils of Burseraceae and their biological properties

Species	Part used	Compounds	Activity	Reference
Aucoumea klaineana Pierre	Resin	α-pinene, α-phellandrene, *p*-cymene and 1,8-cineole	Antiradical, antioxidant and anti-inflammatory	21
	Resin	*p*-acetyl anisole (single benzenic compound), -3-carene, *p*- cymene, limonene, terpinolene and _-terpineol	Antioxidant	8
	Resin	α-pinene, β-pinene, limonene, α-phellandrene, β-phellandrene, 3-carene,α-terpineol, *p*-cymene, eucalyptol	-	68
Boswellia rivae Engler	Resin	Limonene	-	23
Boswellia ameero Balf.f	Resin	(E)-2,3-epoxycarene, 1,5-isopropyl-2-methylbicyclo[3.1.0]hex-3-en-2-ol, and a-cymene, (3E,5E)-2,6-dimethyl-1,3,5,7-octatetraene, 1-(2,4-Dimethylphenyl)ethanol, 3,4-dimethylstyrene, α -campholenal and α -terpineol	Antioxidant and anticholinesterase activity	63
Boswellia carterii Birdw.	Oleogum resin	Isoincensole and isoincensole acetate	Best antifungal	24
	Resin	verticilla-4(20),7,11-triene	-	69
Boswellia dalzielii Hutch	Dried leaf	α-pinene and α-terpinene	-	70
Boswellia dioscorides Thul. & Gifri	Bark	α-thujene and α-pinene	Antimicrobial and antioxidant	57
Boswellia elongata Balf. f.	Resin	Diterpene verticiol, the sesquiterpene caryophyllene and methyl cyclo undecane carboxylate	Antioxidant and anticholinesterase activity	63
	Bark	Incensol	Antimicrobial and antioxidant	57
Boswellia frereana Birdw.	Resin	*p*-cymene	-	71
Boswellia neglecta S. Moore	Resin	*α*-Thujene, *α*-pinene and terpinen-4-ol	-	23
Boswellia papyrifera (Delile ex Caill.) Hochst.	Oleogum resin	Isoincensole and isoincensole acetate along with n-octanol and n-octyl acetate	Best antifungal	24
	Resin	-	Inhibited *Staphylococcus epidermidis* and *Staphylo coccus aureus* biofilms	54
	Branch	-	Antimicrobial	56
Boswellia pirotta Chiov.	Resin	*trans*-verbenol and terpinen-4-ol	-	23
Boswellia rivae Engler	Oleogum resin	Hydrocarbon and oxygenated monoterpenes	*Candida albicans*	24
	Resin	-	Active against preformed *Candida albicans* biofilms	54
Boswellia sacra Flueck.	Resin	*E*-β-ocimene and limonene and *E*-caryophyllene	-	72

	Resin	Boswellic acids	Anti cancer	60
	Branch	-	Antimicrobial	56
	Resin	*α* -Pinene	Antibacterial	73
Boswellia serrata Roxb.	Oleogum resin	Isoincensole and isoincensole acetate	-	24
	Resin	*α*-Thujene	-	74
	Bark	α-pinene	-	22
	Resin	α-thujene	-	75
Boswellia socotrana Balf. f.	Resin	(E)-2,3-epoxycarene, 1,5-isopropyl-2-methylbicyclo[3.1.0]hex-3-en-2-ol, and a-cymene, (3E,5E)-2,6-dimethyl-1,3,5,7-octatetraene, 1-(2,4-Dimethylphenyl)ethanol, 3,4-dimethylstyrene, a-campholenal and a-terpineol	Antioxidant and anticholinesterase activity	63
	Bark	*p*-cymene, 2-hydroxy-5-methoxy-acetophenone and camphor	Antimicrobial and antioxident	57
Bursera aromatica Proctor	Stems, Leaves, Fruits	-	Antimicrobial	53
Bursera chemapodicta Rzed. & E.Ortíz	Leaves	Alkanes and alkanoic derivatives like heptane	-	76
Bursera copallifera (DC.) Bullock	Leaves	Germacrene D	-	77
Bursera excelsa (Kunth) Engl.	Leaves	Germacrene D	-	77
Bursera fagaroides var. *purpusii* (Brandegee) McVaugh & Rzed.	Leaves	Germacrene D	-	77
Bursera graveolens Triana & Planch.	Stem	Limonene and α- terpineol	-	78
Bursera lunanii (Spreng) Adams & Dandy	Fruit	-	Antimicrobial	53
Bursera microphylla A. Gray	Resins	Î²-caryophyllene and myrcene	-	79
Bursera mirandae C.A.Toledo	Leaves	Germacrene D	-	77
Bursera ruticola	Leaves	Germacrene D	-	77
Bursera simaruba (L.)	Fruits, stems	-	Antimicrobial	53
	Leaves	Limonene, β-caryophyllene, α-humulene and germacrene D	Anticancer	58
Bursera velutina Bullock	Leaves	2-Phenylethanol	-	80
*Canarium album (*Lour.*)* Raeusch.	Resin	*β*-pinene, *α*-terpinene, *γ*-terpinene, and terpinen-4-ol	-	26
Canarium schweinfurthii Engl.	Resin	Octyl acetate and nerolidol	Analgesic	25
	Resin	*p*-cymene, limonene and *α*-terpineol	Antiradical, antioxidant and anti-inflammatory	21
Cedrelopsis grevei Baill.	Leaf	(*E*)-*β*-farnesene, *δ*-cadinene, *α*-copaene and *β*-elemene	Anticancer, antiinflammatory, antioxidant and antimalarial	28
	Bark	monoterpenes, sesquiterpene hydrocarbons and oxygenated derivatives	-	27
Commiphora africana (A. Rich.) Engl.	Leaf	bisabolol and β-sesquiphellandrene	Radical scavenging activity	30
	Leaf	α-oxobisabolene and γ-bisabolene	-	29
Commiphora guidottii Chiov.	Gum	(*E*)-*β*-ocimene	-	23
Commiphora habessinica (Berg.) Engl	Resin	β-elemene, α-selinene, cadina-1,4-diene, germacrene B, α-copaene, t-muurolol, caryophyllene oxide and α-cadinol	-	34
Commiphora molmol (Engl.) Engl. ex Tschirch;	Commercial product	dl-Limonene	Larvicidal (*Culex pipiens*)	33
Commiphora mukul (Hook. ex Stocks) Engl.	Oleo-gum-resin	sesquiterpenoids	Antibacterial	51
Commiphora myrrha (Nees) Engl	Resin	Isofuranogermacrene, lindestrene, furanoeudesma-1,3-diene, and furanodiene	-	81
	Resin	Furanoeudesma -1,3-diene	-	23
	Oleo-gum resin	Furanoeudesma-1,3-diene, lindestrene, curzerene, and germacrone,	-	82
	Resin	Curzerene, furanoeudesma-1,3-diene, β-		31

		elemene and 2-0-acetyl-8,12-epoxygermacra-1(10),4,7,11-tetraene, isomer	-	
Commiphora quadricincta Schweinf. ex Engl.	Whole plant	Terpenoids	Accelerates the maturation of immature adults of the desert *Schistocerca gregaria*	67
Dacryodes edulis (G. Don) H. J. Lam	Resin	Sabinene, terpinene-4-ol, α α α α-pinene and *p* -cymene	Antioxidant and antimicrobial	37
	Resin	sabinene, terpinene-4-ol, α α α α -pinene and *p* -cymene	Antioxidant and antimicrobial	38
	Fruit	Myrcene	-	35
	Leaf	β-caryophyllene	-	35
	Stem bark	terpinen-4-ol and a mixture of α-thujene and α-pinene	-	35
	Root bark	α-phellandrene	-	35
	fruit/seed	*α*-pinene, *β*-pinene, limonene and *α*-phellandrene	-	36
Canarium luzonicum (Blume) A.Gray	Resin	α- and β-amyrin	-	83
Mexican copal	Resin	α- and β-amyrin, hop-22(29)-en-3β-ol	-	83
Commiphora molmol Engl.	Resin	Lindestrene, furanoeudesma-1,3-diene and furanoeudesma-1,4-diene-6-one	-	84
Protium altsonii Sandwith	Resin	*p*-cymene, trans-dihydro-α-terpineol	-	44
Protium bahianum Daly	Fruit	α-pinene	Repellent to *Tetranychus urticae*	66
	Leaf	Aromadendrene	Lethal to *Tetranychus urticae*	66
	Leaf	Sesquiterpene followed by monoterpenes and benzenoids	-	85
Protium crassipetalum Cuatrec.	Leaves, branches	α-copaene and *trans*-caryophyllene	-	45
	Leaf	spathulenol	-	45
Protium decandrum (Aubl.) Marchand	Leaf, thin branches	α-pinene	-	44
	Leaf	Tenpin-4-ol	-	86
	Branches, resin	*Trans*-α-bergamotene	-	86
Protium heptaphyllum (Aubl.) March.	Leaf	Terpinolene, β-elemene and β-caryophyllene	-	44
	Resin	Terpinolene	-	44
	Leaf	Myrcene, β-caryophyllene	-	41
	Resin	α-pinene, limonene, α-phellandrene, and terpinolene	-	41
	Fruit	α-pinene	-	41
	Leaves	Terpinolene, β-elemene and β-caryophyllene,	-	87
	Stem	Terpinolene	-	87
	Fruits	α -terpinene	Toxicity and repellence against *Tetranychus urticae*	42
	Leaf	9-epi-caryophyllene, *trans*-isolongifolanone and 14-hydroxi-9-*epi*-caryophyllene	Toxicity against *Tetranychus urticae*	42
Protium heptaphyllum subsp. *heptaphyllum*	Resin	*p* -cymene	-	88
Protium heptaphyllum subsp. *ulei*	Resin	Terpinolene,	-	88
Protium heptaphyllum subsp. *ulei*	Leaf	α-copaene, *trans*-caryophyllene and germacrene B	-	45
Protium icicariba (DC.) Marchand	Resin	*p*-cymene, α-pinene, α-terpinolene and limonene	-	43
	Fruit	Monoterpenes of terpinolene-type	-	43
	Leaf	α-copaene, γ-elemene and δ-cadinene	-	43
Protium pilosissimum Engl.	Branches	selin-11-en-4-α-ol	-	45
Protium pilosum (Cuatrec.) DC.	Leaf, thin branches	α-pinene, *p*-cymene and α-phellandrene	-	44
Protium polybotryum (Turcz.) Engl.	Leaf, Branches	Khusimone	-	45
Protium spruceanum (Benth.) Engl.	Leaf, resin and thin branches	Sabinene, *β*-caryophyllene	-	89
	Leaf, thin branches	Sabinene	-	44
Protium strumosum DC.	Resin	Limonene	-	44
Protium unifoliolatum Engl.	Leaf	Trans caryophyllene, limonene, α - humulene	-	90
Protium spp.	Resin	Monoterpenes and phenylpropanoids		39

Protium spp.	Resin	*p*-cymene and α- and β-phellandrene	-	40
Protium spp.	Leaf	Sesquiterpenes	-	39
Protium pilosissimum Engl.	Leaf	β-sesquiphellandrene	-	45
Santiria trimera (Oliv.) Aubrév	Leaf	α -humulene and β -caryophyllene	*Bacillus cereus* and *Enterococcus faecalis*	47
	Bark	α -pinene and α -terpineol	*Proteus mirabilis*	47
	Bark	α -pinene and β -pinene	*Proteus vulgaris* and *Cryptococcus neoformans*	46

Pharmacological studies
In the recent scenario aromatic plants are widely studied for their large therapeutic potential and benefits. These benefits for human beings are largely due to the presence of essential oils [48]. The essential oils extracted from various members of Burseraceae exhibited significant pharmacological properties which are depicted below.

Analgesic
At the doses of 1, 2 and 3 ml/kg i.p. essential oil of *Canarium schweinfurthii* shows a significant analgesic effect against acetic acid-induced writhing and hot plate models [25].

Antibacterial
Antibacterial properties of *Cinnamomum* and *Boswellia* sp. essential oils were evaluated and their significant activity with MIC values was observed in the range of 64-128 µg/ml and 2-80 mg/ml respectively [49]. Essential oils from *Commiphora ornifolia* and *Commiphora parvifolia* exhibited moderate to high antibacterial activity especially against Gram-positive bacteria [50]. The essential oil extracted from the oleo-gum-resin of *Commiphora mukul* showed a wide range of inhibiting activity against both Gram (+) and Gram (−) bacteria [51]. The oil of *Dacryodes buettneri* exhibited significant antibacterial activity against almost all the microorganisms (*Bacillus cereus*, *Enterococcus faecalis*, *Escherichia coli*, *Listeria innocua*, *Salmonella enterica*, *Shigella dysenteria*, *Staphylococcus aureus*, *Proteus mirabilis*, *Staphylococcus aureus*, *Staphylococcus camorum* and some clinical strains like *E. faecalis*, *Pseudomonas aeruginosa, S. aureus,*) tested, however it was unable to inhibit growth of *Streptococcus pyogenes* [52]. The oil of *Dacryodes edulis* showed significant activity against all the tested bacterial species [37, 38]. The oil extracted from fruits and stems of *Bursera simaruba* and from the fruit of *B. lunanii* were active against all the pathogens tested [53]. The essential oil extracted from the bark of *Santiria trimera* was active against all the bacterial strains, except *Staphylococcus epidermidis*. It exhibited significant antimicrobial activity against *Proteus vulgaris* and *Cryptococcus neoformans* with MICs values of 1.11 microl/ml and lower than 0.71 microl/ml, respectively [46]. The oil obtained from *Boswellia papyrifera* showed considerable activity against both *Staphylococcus epidermidis* and *Staphylococcus aureus* biofilms [54]. They also showed an evident anti-biofilm efficacy against *S. epidermidis* biofilms by using live/dead staining in combination with fluorescence microscopy, Water-distilled essential oils from leaves and bark of *Santiria trimera* were evaluated for their antibacterial activity. The Gram-negative bacteria were the less sensitive to the leaf essential oil, which was effective against *Bacillus cereus* and *Enterococcus faecalis*. The bark essential oil was more active and, in particular, exhibited significant antimicrobial activity against *Proteus mirabilis*, which was resistant to the leaf oil [47]. The volatile oils obtained from *Boswellia thurifera* exhibited considerable inhibitory effect against 25 different genera of bacteria which include animal and plant pathogens, food poisoning and spoilage organisms [55]. Abdoul-latif et al. reported that the significant antimicrobial activity of essential oil and methanol extract of *Boswellia* against all the tested bacterial species [56]. Essential oils obtained from *Boswellia* species (*Boswellia dioscorides*, *Boswellia elongata* and *Boswellia socotrana*) exhibited antimicrobial activity especially against Gram-positive bacteria with MIC-values ranged in between 1.8 and 17.2 mg/ml [57].

Anticancer
The anticancer activity of the essential oil was tested on human lung carcinoma cell line A-549 and human colon adenocarcinoma cell line, DLD-1. *Bursera simaruba* leaf essential oil was found to be active against both tumor cell lines, with a GI50 of 42 ± 2 µg/mL for A-549 and 48 ± 2 µg/mL for DLD-1. The cytotoxic properties of the major constituents of the oil indicates that α-humulene is possibly responsible for this activity [58] *Cedrelopsis grevei* essential oil was active against *MCF-7* cell lines of human breast cancer cells (IC_{50} = 21.5 mg/L) [28]. *Commiphora gileadensis* stem essential oil has an antiproliferative proapoptotic effect against tumor cells but not against normal cells. *β*-caryophyllene caused a potent induction of apoptosis accompanied by DNA ladder and caspase-3 catalytic activity in tumor cell lines [59]. All human breast cancer cell lines were sensitive to essential oil treatment with reduced cell viability and elevated cell death which may be due to presence of boswellic acids in essential oils of *Boswellia sacra* [60], whereas the immortalized normal human breast cell line was more resistant to essential oil treatment. *Boswellia sacra* essential oil hydrodistilled at 100 ºC was more potent than the essential oil prepared at 78 ºC in inducing cancer cell death, preventing the cellular network formation of cells on matrigel, causing the breakdown of multicellular tumor spheroids, and regulating molecules involved in apoptosis, signal transduction, and cell cycle progression.

Antifungal
Among different *Boswellia* species (*B. carteri*, *B. papyrifera*, *B. serrata* and *B. rivae*) oleogum resin essential oils tested for antifungal activity, the essential oils with the best activity against fungal strains were those obtained from *B. carteri* and *B. papyrifera* with MIC values as low as 6.20 microg/ml. The essential oil of *B. rivae* resin showed the best activity against *C. albicans* with a MIC value of 2.65 microg/ml [24]. *Boswellia rivae* essential oil was very active against preformed *C. albicans* biofilms and inhibited the formation of *C. albicans* biofilms at a sub-MIC concentration [54]. The essential oils were found more efficacious than some prevalent organic preservatives *viz.* salicylic acid, BHT, ascorbic acid and gallic acid as they inhibited the growth and aflatoxin secretion of the aflatoxigenic strain *Aspergillus flavus* even at a lower concentration [61]. The food preservative potential of plant

essential oils (*Origanum majorana*, *Coriandrum sativum*, *Hedychium spicatum*, *Commiphora myrrha* and *Cananga odorata*) were evaluated based on their antifungal, antiaflatoxin properties [61]. The LC_{50} value of all the essential oils ranged in between 1.3 and 21.67 µl/ml while their total phenolic content ranged between 2.90 and 33.33 µg/mg [61]. They found that the minimum inhibitory concentration of EOs against the toxigenic strain of *A. flavus* ranged in between 2 and 3 µl/ml. In addition, the EOs exhibited broad fungitoxic spectrum against nine food borne molds. The essential oil extracted from the bark of *Santiria trimera* was active against all the fungal strains, except *Aspergillus niger* [46]. The essential oil obtained from the leaf and fruit of *Santiria trimera* exhibited a weak anticandidal effect [47].

Anti-inflammatory

Significant anti-inflammatory activity was shown by *Cedrelopsis grevi* with IC_{50} of 21.33 mg/L [28]. Essential oil of *Canarium schweinfurthii* was unable to reduce inflammation in cotton pellet induced granuloma models [25]. The anti-inflammatory activity was carried out by lipoxygenase method, *Canarium schweinfurthii* was the only active oil with an IC₅₀ of 62.6ppm [21]

Antioxidant

The radical scavenging activity of *Commiphora africana* oil was found to be low when compared to that of butylated hydroxytoluene [30]. The essential oil of *Cedrelopsis grevi* exhibited poor antioxidant activity against DPPH (IC_{50} > 1000 mg/L) and ABTS (IC_{50} = 110 mg/L) assays [28]. The radical scavenging activity of the oils of *Canarium schweinfurthii* and *Aucoumea klaineana* was evaluated by spectrophotometry using DPPH. Among both the oils, *A. klaineana* was found to be more active with SC₅₀ value of 23.7g/l. The antioxidant potential was also evaluated by a β-carotene/linoleate and noticed that *C. schweinfurthii* was not active and the IC₅₀ of *A. klaineana* and *C. schweinfurthii* were 9.0 and 51.3mg/l respectively [21]. The DPPH-radical scavenging assay exhibited only weak antioxidant activities for both oils (*Commiphora ornifolia* and *Commiphora parvifolia)* even at high concentrations [50]. The potent antioxidant activity was shown by oils from species such as *Origanum majorana*, *Coriandrum sativum*, *Hedychium spicatum*, *Commiphora myrrha* and *Cananga odora* [61]. The essential oil of *Aucoumea klaineana* and *Dacryodes buettneri* exhibited significant antioxidant and DPPH radical scavenging activities and they displayed the inhibition of lipid peroxidation [8, 52]. In the DPPH test, the IC_{50} value of *Dacryodes edulis* oil was in the range of 68.5 ± 2.29 µg/ml, whereas in β- carotene-linoleic acid test, oxidation of linoleic acid was effectively inhibited by *Dacryodes edulis* (70.0%). However the oil was less effective than BHT [97]. The resin exudates of *Commiphora wightii* showed significant antioxidant activity under *in vitro* conditions [62]. The antioxidant activity of essential oil from *Boswellia socotrana* (IC_{50} =121.4 µg/mL) appeared to be more potent than that of *B. elongata* (IC_{50} =211.2 µg/mL) and *B. ameero* (IC_{50} =175.2 µg/mL) [63]. Oils obtained from *B. socotrana* showed the higher anticholinesterase inhibitory activity with 59.3% at concentration of 200 µg/mL in comparison to essential oil of *Boswellia elongata* and *Boswellia ameero* (29.6, 41.6 enzyme inhibition) respectively [63]. Essential oils obtained from *Boswellia* species (*B. dioscorides*, *B. elongata* and *B. socotrana*) exhibited only weak antioxidant activities (28%) at 1.0 mg/ml [57].

Insecticidal and larvicidal

Cedrelopsis grevei oil was active against *Plasmodium falciparum*, (IC_{50} = 17.5 mg/L) which representing its great antimalarial property [28]. *Commiphora molmol* exhibited lower activity against *Culex pipiens* larvae with LC_{50}, LC_{75} and LC_{90} values of 0.992, 2.177 and 4.419 respectively [33]. Larvicidal activity of essential oils derived from 11 aromatic medicinal plants against early 4th-stage larvae of *Aedes aegypti* and *Culex pipiens* was tested [64]. They found that at 100 ppm, the essential oils obtained from all plants exhibited 100% mortality against both the larvae. The acaricidal activities of *Protium bahianum* resin oil against *Tetranychus urticae* were investigated and found that the oils showed fumigant toxicity (mortality and fecundity), but only the aged resin oil induced repellence [65]. The fruit oil obtained from *Protium heptaphyllum* was found to be more effective against the mite (*T. urticae*) when compared to the leaf oil. However both showed mortality properties and oviposition deterrence in higher concentration (10 $\mu l.l^{-1}$ air), but only the essential oil extracted from fruits induced repellence on *T. urticae* [42]. The leaf oil of *P. bahianum* exhibited a higher lethality rate against *T. urticae* with LC_{50} of 3.5 µL/L after 24 h exposure. The fruits oil showed LC_{50} of 9.1 µL/L and was repellent at 1% concentration [66].

Influence on maturation

Extracts from *Commiphora quadricincta* were tested for their effects on the maturation of gregarious immature males and females of the desert locust, *Schistocerca gregaria* [67]. Maturation was significantly faster in immature adults exposed to the extract obtained before winter rains than in those exposed to the extract obtained after the rains, with respect to locust colour changes (yellowing of body), mating activity, aggregation-maturation pheromone titres (as measured by phenylacetonitrile levels in males), ovulation (as determined by the length of oocytes in females) and oviposition time.

Acknowledgements

The receipt of financial assistance from the Council of Scientific and Industrial Research (CSIR), New Delhi, is gratefully acknowledged

References

1. Daly DC, Harley MM, Martínez-Habibe MC. A. Weeks, Burseraceae. Flowering plants. Eudicots, the families and genera of vascular plants 2011; 10:76-104.
2. Cronquist A. An integrated system of classification of flowering plants. Columbia University press. New York, 1981, 803.
3. Costa AF. Farmacognosia, Fundacao calouste Gulbenkian, Lisboa 1975; 1:9.06-959.
4. Bruneton J. Eléments de phytochimie et de pharmacognosie. Technique et Documentation, Lavoisier, Paris, France, 1987.
5. Masotti V, Juteau F, Bessiere JM, Viano J. Seasonal and phenological variations of the essential oil from the narrow endemic species *Artemisia molinieri* and its biological activities. J Agric Food Chem. 2003; 51:7115-7121.
6. Angioni A, Barra A, Coroneo V, Dessi S, Cabras P. Chemical composition, seasonal variability and antifungal activity of *Lavandula stoechas* L. ssp. *stoechas* essential

oils from stem/leaves and flowers. J Agric Food Chem. 2006; 54:4364-4370.
7. Bertoli A, Cirak C, Silva JATD. *Hypericum* species as a source of volatile essential oils. Medicinal Aromatic Plant Sci. Biotech 2011; 5:29-47.
8. Koudou J, Obame LC, Kumulungui BS, Edou P, Figueredo G, Chalchat JC *et al*. Volatile constituents and antioxidant activity of *Aucoumea klaineana* Pierre essential oil. Afr. J Pharm Pharmacol. 2009; 3:323-326.
9. Siddiqui MZ. *Boswellia serrata*, a potential antiinflammatory agent: An overview. Indian J Pharm Sci. 2011; 73:255-261
10. Mahe A, Khan H, Samiullah L, Siddique KM. A review on phytochemical and pharmacological studies of Kundur (*Boswellia serrata* Roxb ex Colebr.) -A Unani drug, Journal of Applied Pharmaceutical Science. 2012; 2:148-156.
11. Kerhaho J. La Pharmacopée sénégalaise traditionnelle: plantes médicinales et toxiques. Editions Vigot Frères, Paris 1974, 395-399.
12. Rakotobe M, Menut C, Andrianoelisoa HS, Rahajanirina V, Chatelperron PCD, Roger E *et al*. The bark essential oil composition and chemotaxonomical appraisal of *Cedrelopsis grevei* H. Baillon from Madagascar. Nat. Prod. Commun 2008; 3:1145-1150.
13. Hines DA, Eckman K. Indigenous multipurpose trees of Tanzania: uses and economic benefits for people Ottawa: Cultural Survival Canada and Development Services Foundation of Tanzania, 1993.
14. Hedberg I, Hedberg O, Madati PJ, Mshigeni KE, Mshiu EN, Samuelsson G. Inventory of plants used in traditional medicine in Tanzania. I. Plants of the families Acanthaceae-Cucurbitaceae. J Ethnopharmacol. 1982; 6:29-60.
15. Kuppurajan K, Rajagopalan SS, Rao TK, Sitaraman R. Effect of guggulu (*Commiphora mukul* Engl.) on serum lipids in obese, hypercholesterolemic and hyperlipemic cases. J Assoc Physicians India. 1978; 26:367-373.
16. Singh RB, Niaz MA, Ghosh S. Hypolipidemic *Commiphora mukul* therapy in patients and antioxidant effects of as an adjunct to dietary with hypercholesterolemia. Cardiovasc. Drug. ther 1994; 8:659-664.
17. Khanna N, Arora D, Halder S, Mehta AK, Garg GR, Sharma SB *et al*. Comparative effect of *Ocimum sanctum*, *Commiphora mukul*, folic acid and ramipril on lipid peroxidation in experimentally-induced hyperlipidemia. Indian J Exp Biol. 2010; 48:299-305.
18. Mogana R, Wiartc *Canarium* L. A phytochemical and pharmacological review. J Pharm Res. 2011; 4:2482-2489.
19. Ajibesin KK. *Dacryodes edulis* (G. Don) H. J. Lam: a review on its medicinal, phytochemical and economical properties. Res. J Med Plant. 2011; 5:32-41.
20. Rüdiger AL, Sianib AC, Juniora VFV. The chemistry and pharmacology of the South America genus *Protium* Burm. f. (Burseraceae). Pharmacognosy Reviews. 2007; 1:93-104.
21. Michel JDP, François T, Bernadin N, Wilson A, Bertrand S, Amvam ZPH *et al.* Chemical characterization, antiradical, antioxidant and anti-inflammatory potential of the essential oils of *Canarium schweinfurthii* and *Aucoumea klaineana* (Burseraceae) growing in Cameroon. Agr. Biol. J N Am. 2010; 1:606-611.
22. Kasali AA, Adio AM, Oyedeji AO, Eshilokun AO, Adefenwa M. Volatile constituents of *Boswellia serrata* Roxb. (Burseraceae) bark. Flavour Fragr. J. 2002; 17:462-464.
23. Başer KHC, Demirci B, Dekebo A, Dagne E. Essential oils of some *Boswellia* spp., Myrrh and Opopanax. Flavour Fragr. J. 2003; 18:153-156.
24. Camarda L, Dayton T, Di Stefano V, Pitonzo R, Schillaci D. Chemical composition and antimicrobial activity of some oleogum resin essential oils from *Boswellia* spp. (Burseraceae). Ann. Chim 2007; 97:837-844.
25. Koudou J, Abena AA, Ngaissona P, Bessiere JM. Chemical composition and pharmacological activity of essential oil of *Canarium schweinfurthii*. Fitoterapia 2005; 76:700-703.
26. Giang PM, Konig WA, Son PT. Chemical composition of the resin essential oil of *Canarium album* from Vietnam. Chem. Nat. Comp 2006; 42:523-524.
27. Rakotobe M, Menut C, Andrianoelisoa HS, Rahajanirina V, Tsy JMLP, Rakotoarimanana V *et al.* Bark essential oil of *Cedrelopsis grevei* from Madagascar: investigation of steam-distillation conditions. Chem. Biodiv. 2014; 11:323-331.
28. Afoulous S, Ferhout H, Raoelison EG, Valentin A, Moukarzel B, Couderc F *et al.* Chemical composition and anticancer, antiinflammatory, antioxidant and antimalarial activities of leaves essential oil of *Cedrelopsis grevei*. Food Chem. Toxicol 2013; 56:352-362.
29. Ayédoun MA, Sohounhloué DK, Menut C, Lamaty G, Molangui T, Casanova J *et al.* Aromatic plants of tropical West Africa. VI. α-Oxobisabolene as main constituent of the leaf essential oil of *Commiphora africana* (A. Rich.) Engl, from Benin. J Essent Oil Res. 1998; 10:105-107.
30. Avlessi F, Alitonou GA, Sohounhloue DK, Bessiere JM, Menut C. Aromatic Plants of Tropical West Africa. Part XV. Chemical and biological evaluation of leaf essential oil of *Commiphora africana* from Benin. J Essent Oil Res. 2005; 17:569-571.
31. Morteza-Semnani K, Saeedi M. Constituents of the essential oil of *Commiphora myrrha* (Nees) Engl. var. *molmol.* J Essent Oil Res. 2003; 15:50-51.
32. Ogunwande IA, Saroglou V, Skaltsa E, Ogunbinu AO, Kubmarawa D. Constituents of some essential oil bearing plants from Nigeria. J Essent Oil Res. 2009; 21:61-66.
33. Habeeb SM, El-Namaky AH, Salama MA. Efficiency of *Allium cepa* and *Commiphora* molmol as a larvicidal agent against fourth stage larvae of *Culex pipiens* (Diptera: Culicidae. American-Eurasian Journal of Agricultural and Environmental Science. 2009; 5:196-203.
34. Ali NAA, Wurster M, Lindequist U. Chemical composition of essential oil from the oleogum resin of *Commiphora habessinica* (Berg.) Engl. from Yemen. J Essent Oil Bear Plant. 2009; 12:244-249.
35. Onocha PA, Ekundayo O, Oyelola O, Laakso I. Essential oils of *Dacryodes edulis* (G. Don) H. J. Lam (African pear). Flavour Fragr. J. 1999; 14:135-139.
36. Jirovetz L, Buchbauer G, Ngassoum MB, Parmentier M. Chemical composition and olfactory characterization of essential oils of fruits and seeds of African pear (*Dacryodes edulis* (G. Don) H. J. Lam) from Cameroon. Flavour Fragr. J. 2005; 20:215-218.
37. Obame LC, Edou P, Bassolé IHN, Koudou J, Agnaniet H, Eba F. Chemical composition, antioxidant and antimicrobial properties of the essential oil of *Dacryodes*

edulis (G. Don) H. J. Lam from Gabon. Afr. J Microbiol Res. 2008; 2:148-152.
38. Koudou J, Edou P, Obame LC, Bassole IH, Figueredo G, Agnaniet H *et al.* Volatile components, antioxidant and antimicrobial properties of the essential oil of *Dacryodes edulis* G. Don from Gabon. J App Sci. 2008; 8:3532-3535.
39. Siani AC, Ramos MFS, Menezes-de-Lima JO, Ribeiro-dos-Santos R, Fernadez-Ferreira E, Soares ROA *et al.* Henriques, Evaluation of anti-inflammatory-related activity of essential oils from the leaves and resin of species of *Protium*. J Ethnopharmacol. 1999; 66:57-69.
40. Ramos MFS, Siani AC, Tappin MRR, Guimarães AC, Ribeiro JELDS. Essential oils from oleoresins of *Protium* spp. of the Amazon region. Flavour Fragr. J. 2000; 15:383-387.
41. Bandeira PN, Machado MIL, Cavalcanti FS, Lemos TLG. Essential oil composition of leaves, fruits and resin of *Protium heptaphyllum* (Aubl.) March. J Essent Oil Res. 2001; 13:33-34.
42. Pontes WJT, Oliveira JCGD, Câmara CAGD, Lopes ACHR, Júnior MGCG, Oliveira JVD *et al.* Chemical composition and acaricidal activity of the leaf and fruit essential oils of *Protium heptaphyllum* (Aubl.) Marchand (Burseraceae). Acta Amaz. 2007[a]; 37:103-110.
43. Siani AC, Garrido IS, Monteiro SS, Carvalho ES. Ramos MFS. *Protium icicariba* as a source of volatile essences. Biochem. Syst. Ecol. 2004; 32:477-489.
44. Zoghbi MDGB, Andrade EHA, Lima MDP, Silva TMD, Daly DC. The essential oils of five species of *Protium* growing in the North of Brazil. J Essent Oil-Bear Plant. 2005; 8:312-317.
45. Carvalho LED, Magalhães LAM, Lima MDP, Marques MOM, Facanali R. Essential oils of *Protium* of the Adolpho ducke forest reserve: *Protium crassipetalum*, *P. heptaphyllum* subsp. *ulei*, *P. pilosissimum* and *P. polybotryum*. J Essent Oil-Bear Plant. 2013; 16:551-554.
46. Martins AP, Salgueiro LR, Gonçalves MJ, Cunha APD, Vila R, Cañigueral S. Essential oil composition and antimicrobial activity of *Santiria trimera* Bark. Planta Med. 2003; 69:77-79.
47. Bikanga R, Makani T, Agnaniet H, Obame LC, Abdoul-Latif FM, Lebibi J *et al.* Chemical composition and biological activities of *Santiria trimera* (Burseraceae) essential oils from Gabon. Nat. Prod. Commun. 2010; 5:961-964.
48. Asgarpanah J, Ziarati P, Safialdinardebil M. The volatile oil composition of *Rosa foetida* Herrm. flowers growing wild in Kurdistan province (Iran). J Essent Oil-Bear Plant. 2014; 17:169-172.
49. Shareef AA. Evaluation of antibacterial activity of essential oils of *Cinnamomum* sp. and *Boswellia* sp. Journal of Basrah Researches (Sciences). 2011; 37:60-71.
50. Mothana RA, Rehaily AJA, Schultze W. Chemical analysis and biological activity of the essential oils of two endemic soqotri *Commiphora* species. Molecules. 2010; 15:689-698.
51. Saeed MA, Sabir AW. Antibacterial activities of some constituents from oleo-gum-resin of *Commiphora mukul*. Fitoterapia. 2004; 75:204-208.
52. Obame LC, Koudou J, Chalchat JC, Bassolé I, Edou P, Ouattara AS *et al.* Volatile components, antioxidant and antibacterial activities of *Dacryodes* buettneri H. J. Lam. essential oil from Gabon. Sci Res Essays. 2007; 2:491-495.
53. Junor GO, Porter RBR, Facey PC, Yee TH. Investigation of essential oil extracts from four native Jamaican species of *Bursera* for antibacterial activity. West Indian Med. J 2007; 56:22-25.
54. Schillaci D, Arizza V, Dayton T, Camarda L, Stefano VD. *In vitro* anti-biofilm activity of *Boswellia* spp. oleogum resin essential oils. Lett. Appl. Microbiol 2008; 47:433-438.
55. Baratta MT, Dorman HJD, Deans SG, Figueiredo AC, Barroso JG, Ruberto G. Antimicrobial and antioxidant properties of some commercial essential oils. Flavour Fragr. J 1998; 13:235-244.
56. Abdoul-latif FM, Obame LC, Bassolé IHN, Dicko MH. Antimicrobial activities of essential oil and methanol extract of *Boswellia sacra* Flueck. and *Boswellia papyrifera* (Del.) Hochst from Djibouti. International Journal of Management, Modern Sciences and Technologies. 2012; 1:1-10.
57. Mothana RAA, Hasson SS, Schultze W, Mowitz A, Lindequist U. Phytochemical composition and in vitro antimicrobial and antioxidant activities of essential oils of three endemic soqotraen *Boswellia* species. Food Chem 2011; 126:1149-1154.
58. Sylvestre M, Longtin APA, Legault J. Volatile leaf constituents and anticancer activity of *Bursera simaruba* (L.) Sarg. essential oil. Nat. Prod. Commun. 2007; 2:1273-1276.
59. Amie E, Ofir R, Dudai N, Soloway E, Rabinsky T, Rachmilevitch S. β-Caryophyllene, a compound isolated from the biblical balm of gilead (*Commiphora gileadensis*), is a selective apoptosis inducer for tumor cell lines. J Evid Based Complementary Altern Med. 2012, 1-8.
60. Suhail MM, Wu W, Cao A, Mondalek FG, Fung KM, Shih PT *et al. Boswellia* sacra essential oil induces tumor cell specific apoptosis and suppresses tumor aggressiveness in cultured human breast cancer cells. BMC complex. Altern. M 2011; 11:129-136.
61. Prakash B, Singh P, Kedia A, Dubey NK. Assessment of some essential oils as food preservatives based on antifungal, antiaflatoxin, antioxidant activities and *in vivo* efficacy in food system. Food Res. Int 2012; 49:201-208.
62. Siddiqui MZ, Thomas M, Prasa N. Physicochemical characterization and antioxidant activity of essential oils of guggul (*Commiphora* wightii) collected from Madhya Pradesh. Indian J Pharm Sci. 2013; 75:368-372.
63. Ali NAA, Wurster M, Arnold N, Teichert A, Schmidt J, Lindequist U *et al.* Chemical composition and biological activities of essential oils from the oleogum resins of three endemic soqotraen *Boswellia* species. Rec. Nat. Prod. 2008; 2:6-12.
64. Lee HS. Mosquito larvicidal activity of aromatic medicinal plant oils against *Aedes aegypti* and *Culex pipiens* Pallens. J Am Mosq Control Assoc. 2006; 22:292-295.
65. Pontes WJT, Oliveira JCSD, Camara CAGD, Lopes ACHR, Junior MGCG, Oliveira JVD *et al.* Composition and acaricidal activity of the resin's essential oil of *Protium bahianum* Daly against two spotted spider mite (*Tetranychus urticae*). J Essent Oil Res. 2007b; 19:379-383.
66. Pontes WJT, Silva JMO, Camara CAGD, Gondim-Júnior MGC, Oliveira JV, Schwartz MOE. Chemical composition and acaricidal activity of the

essential oils from fruits and leaves of *Protium bahianum* Daly. J Essent Oil Res. 2010; 22:279-282.
67. Assad YOH, Torto B, Hassanali A, Njagi PGN, Bashir NHH, Mahamat H. Seasonal variation in the essential oil composition of *Commiphora quadricincta* and its effect on the maturation of immature adults of the desert locust, *Schistocerca gregaria*. Phytochem. 1997; 44:833-841.
68. Medzegue MJ, Stokes A, Gardrat C, Grelier S. Analysis of volatile compounds in *Aucoumea klaineana* oleoresin by static headspace/gas chromatography/mass spectrometry. J Nat Prod. 2013; 6:81-89.
69. Basar S, Koch A, König WA. A verticillane-type diterpene from *Boswellia carterii* essential oil. Flavour Fragr. J 2001; 16:315-318.
70. Kubmarawa D, Ogunwande IA, Okorie DA, Olawore NO, Kasali AA. Constituents of the essential oils of *Boswellia dalzielii* Hutch. From Nigeria. J Essent Oil Res. 2006; 18:119-120.
71. Strappaghetti G, Corsane S, Craveiro A, Proietti G. Constituents of essential oil of *Boswellia frereana*. Phytochem 1982; 21:2114-2115.
72. Harrasi AA, Saidi SA. Phytochemical analysis of the essential oil from botanically certified oleogum resin of *Boswellia sacra* (Omani Luban). Molecules 2008; 13:2181-2189.
73. Saidi SA, Rameshkumar KB, Hisham A, Sivakumar N, Al-Kindy S. Composition and antibacterial activity of the essential oils of four commercial grades of omani luban, the oleo-gum resin of *Boswellia sacra* Flueck. Chem. Biodiv 2012; 9:615-624.
74. Singh B, Kumar R, Bhandari S, Pathania S, Lal B. Volatile constituents of natural *Boswellia serrata* oleo-gum-resin and commercial samples. Flavour Fragr. J 2007; 22:145-147.
75. Verghese J, Joy MT, Retamar JA, Malinskas GG, Catalán CAN, Gros EG. A fresh look at the constituents of indian olibanum oil. Flavour Fragr. J 1987; 2:99-102.
76. Evans PH, Becerra JX. Non-terpenoid essential oils from *Bursera chemapodicta.* Flavour Fragr. J 2006; 21:616-618.
77. Noge K, Becerra JX. Germacrene D, a common sesquiterpene in the genus *Bursera* (Burseraceae). Molecules 2009; 14:5289-5297.
78. Gary YD, Sue C, Herve C, Marie-Claude B, Danilo M. Essential Oil of *Bursera graveolens* (Kunth) Triana et Planch from Ecuador. J Essent Oil Res. 2007, 19525-526.
79. Arthur OT, Michael JM, Rebecca CB, Leslie RL, Dary L. Essential oils from the oleo-gum-resins of elephant tree or torote (*Bursera* microphylla A. Gray, Burseraceae) from Arizona. J Essent Oil Res. 2009; 21:57.
80. Noge K, Venable DL, Becerra JX. 2-Phenylethanol in the leaves of *Bursera* velutina Bullock (Burseraceae). Acta Bot Mex. 2011; 97:9-16.
81. Maradufu A, Warthen JD. Furano sesquiterpenoids from *Commiphora* myrrh oil. Plant Sci. 1988; 57:181-184.
82. Marongiu B, Piras A, Porcedda S, Scorciapino A. Chemical composition of the essential oil and supercritical CO_2 extract of *Commiphora myrrha* (Nees) Engl. and of Acorus calamus L. J Agric Food Chem. 2005; 53:7939-7943.
83. Cruz-Cañizares JDL, Doménech-Carbó MT, Gimeno-Adelantado JV, Mateo-Castro R, Bosch-Reig F. Study of Burseraceae resins used in binding media and varnishes from artworks by gas chromatography mass spectrometry and pyrolysis gas chromatography mass spectrometry. Journal of Chromatography A. 2005; 1093:177-194.
84. Brieskorn CH, Noble P. Two furanoeudesmanes from the essential oil of myrrh. Phytochem 1983; 22:187-189.
85. Moraes MMD, Camara CAGD, Ramos CS. Seasonal variation in the essential oil of *Protium bahianum* Daly (Burseraceae). J Essent Oil-Bear Plant. 2013; 16:300-307.
86. Carvalho LED, Pinto DDS, Magalhães LAM, Lima MDP, Marques MOM, Facanali R. Chemical constituents of essential oil of *Protium decandrum* (Burseraceae) from Western Amazon. J Essent Oil-Bear Plant. 2010; 13:181-184.
87. Zoghbi MDGB, Maia JGS, Luz AIR. Volatile constituents from leaves and stems of *Protium heptaphyllum* (Aubl.). J Essent Oil Res. 1995; 7:541-543.
88. Delcio DM, Rogério AS, Telma LGL, Luciana LM, João SNDS, Francisco JQM. Chemical composition of the essential oils from two subspecies of *Protium heptaphyllum*. Acta amaz 2010; 40:227-230.
89. Machado LB, Zoghbi MDGB, Andrade EHA. Seasonal variation in the composition of the essential oils from the leaves, thin branches and resin of *Protium spruceanum* (Benth.) Engl. Flavour Fragr. J 2003; 18:338-341.
90. Das MGBZ, Emidio VLDC, Wilson WF. Essential oil of *Protium unifoliolatum* (Burseraceae). Acta amaz. 1993; 23:15-16.