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Review Article

Bioprospecting of Underutilised Mangroves: A Review Based on Bioactive Phytochemicals of Mangroves on Kerala Coast, India

Hridya Vasantha Kavunkal* and Radhakrishnan Kokkuvayil Vasu

Chemical Science and Technology Division, CSIR-NIIST, India

***Corresponding Author:** Hridya Vasantha Kavunkal, Chemical Science and Technology Division, CSIR-NIIST, India.

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Abstract

The mangrove habitat has recently become one of the most promising hotspots for bioprospecting of natural product resources for various therapeutic objectives owing to its highly productive and diverse ecosystem. The adequate information on bioactive substances in mangroves will aid in the long-term monitoring of mangrove species and the design of species-specific conservation measures. Mangroves have come to be recognized as the biological resources because they have specialized biochemical functions, making them abundant factories of secondary metabolites such as flavonoids, alkaloids, tannins, and phenolic compounds. The mangrove species found in Kerala state, India, is the focus of this paper, which also highlights its edibility, bioactive chemicals and their different reported pharmacological effects. Though the medicinal potential of mangrove plants has been the subject of numerous studies, its edibility, socio-economic importance, traditional therapeutic uses, nutritional, and antioxidant properties are still underutilized and underexplored. Mangroves should therefore be protected since they are a valuable resource for humans, particularly because they can be used as an alternative source of food or for traditional medicine alongside to their unique biodiversity, role in maintaining water quality, and contribution to coastal defense.

Keywords: Edible Mangroves; Aegiceras *corniculatum; Avicenna officinalis; Kandelia candel; Rhizophora mucronata; Sonneratia caseolaris*

Introduction

Mangroves are naturally evolved, salt tolerant ecosystem that are mainly found in tropical and subtropical intertidal regions [1]. It occupies around 25% of the world's coastline scattered among 112 countries and territories covering 181,000 sq. km worldwide [2]. There are 84 mangrove species in the world, divided into 12 varieties, 24 genera, and 16 families, of which 14 are semi-mangroves [3]. These species are physiologically a group adapted to the tropics, and they can survive in diverse salinities alongside other plants, like ferns, trees, and shrubs. The State of Forests Report (2019) released by the Government of India estimates that 3 percent of the global mangroves and 8 percent of the Asian mangroves are in India. Indian mangroves comprise 46 true mangrove species, which are divided into 14 families and 22 genera [4]. Of these, 18 species are found in Kerala, grouped into 11 genera and 8 families, as classified [5].

Mangroves are among the most significant bioresources used by various cultures worldwide, but many of the listed mangroves in India, particularly in Kerala, remain neglected and still uncharted due to a lack of scientific knowledge and visibility. The mangrove ecosystems across the globe are in danger as a consequence of unplanned, unscientific development activities and the improper disposal of trash from industries and cities. "Kallan Pokkudan" was a nature lover who spearheaded the conservation of mangroves in Kerala. Mangroves should be preserved because of their distinct biodiversity, benefit to humans, relevance in maintaining water quality, role in creating coastal defences, the power to mitigate cli-

mate change through carbon sequestration, an alternative source of food security, and use in traditional medicine. In recent times, the mangrove ecosystem environment has become one of the most intriguing hotspots for the bioprospecting of natural product resources. Mangroves' potential as a source for innovative bioactive compounds is still completely unexplored, thus it matters mangroves will ensure food and medicine, which will play a key role in the preservation of the mangrove ecosystem in the future. The unique capacity of mangroves to thrive in adverse circumstances has led to multiple physiological modifications, and this may outcome in the generation of secondary metabolites that are crucial for adaptability to a variety of habitat challenges. Mangroves are thus thought of as a source of innovative natural and biological resources and have a specific biochemical activity in their bionetwork system. These novel bioactive chemicals, such as flavonoids, alkaloids, tannins, and phenolic compounds, are abundant throughout these plants. The medicinal potential of mangrove plants has been the focus of many research investigations, including those on their antibacterial [6], antifungal [7], antiviral [8], anticancer [9], antidiabetic [10], antimalarial [11], and anti-inflammatory [12] and antioxidative [13] properties. The chemistry and bioactivities of natural products from the 18 mangrove species found in Kerala are outlined in this article. The comprehensive data on bioactive substances in mangroves provided here might thus contribute in the ongoing monitoring of mangrove species in the Kerala state and the progression of species-specific conservation strategies. As an outcome, the present work attempts to provide a broad overview of the pharmacological characteristics of Kerala mangroves as well as their socioeconomic value and viability for human use.

Review Methodology

The ethnobotany, phytochemistry, and pharmacology of the plant were systematically searched in scientific literature utilising the databases including Google Scholar, PubMed, Science Direct, Mendeley, and ResearchGate. The plant names and details accessed by the databases https://indiabiodiversity.org/ [14], and https://www.marinespecies.org/ [15]. Chemdraw Professional 17.1 from PerkinElmer was used to illustrate chemical structures of the compounds.

Importance of mangroves and its classification

Mangroves are generally classified into true mangroves and mangrove associates. These are again classified into the categories namely, red, black, white/grey, and yellow mangroves. *Rhizophora mucronata* is a Red Mangrove which is characterized by its stilt roots and red-brown bark and is commonly found in estuaries and along closest to the coastline and often growing in the water. Avicennia officinalis is under Grey Mangrove category, which is known for their distinctive greyish-green leaves and pneumatophores (specialized roots for gas exchange), and they thrive in brackish water environments. *Aegiceras corniculatum* are River by their pale-yellow flowers and are typically found along riverbanks in Kerala. *Bruguiera cylindrica* is a brown mud mangrove that have cylindrical fruit capsules and are adapted to grow in muddy areas. *Sonneratia alba* is a Milkwood Mangrove which has white, fragrant flowers and is often found in the backwaters and estuaries of Kerala.

Traditional, nutritional, and medicinal properties of mangroves

Ayurvedic texts state that mangroves have been used for medicinal purposes in India since ancient times. Mangroves have been widely used in folk medicine as a remedy for various ailments [1,16]. Research reports indicate that out of 84 types of mangrove plants discovered so far, only 26 species have been used in scientific studies for medicinal purposes [17]. But all the rest of the mangroves are similarly said to be capable of preventing various diseases in folk medicine. The consistency of metabolic components of mangroves, such as carbohydrates, proteins, vitamins and fat, along with its antioxidative nature due to the abundance of phenolic compounds, limonoids, and their derivatives (Figure 2), enable the consumption of mangrove parts with a benign effect. Various chemical substances (secondary metabolites) present in mangrove plants are produced to survive the adverse environmental conditions in which they grow, so their research will be more useful for the discovery of new types of medicines. If this infinite range of medicinal properties in mangroves can be properly utilized, people will be compelled to protect the mangroves and plant new ones.

Among the 18 mangrove species found in Kerala [18], 10 species have been traditionally ensured as edible food, or as nutritional sources in Asia and other parts of the world. The medicinal benefits of these species include to treat skin diseases, liver diseases, bone injury, lung diseases, cancer, menstrual irregularities, inflammation, rheumatism, snake bite, diabetes, diarrhoea, etc. Additionally, the underutilised edible mangroves give nutrition, and it is essential to generate awareness of the less popular mangrove

fruits that have nutritional substances and economic worth. Herein, we address the bio-prospective evaluation of these 10 edible mangrove species found in Kerala state, India, and their underutilised food qualities.

Acrostichum aureum L

Figure 1: Some of the mangrove plants found in Kerala (1) *Acrostichum aureum*, (2) *Avicenna officinalis*, (3) *Aegiceras corniculatum*, (4) *Bruguiera cylindrica* (5) *Avicennia marina,* (6) *Sonneratia caseolaris* [Sources: Wikipedia and Author photographs].

Acrostichum aureum, an edible mangrove of golden leather fern type Figure 1(1) under the Pteridaceae plant family that largely grows in tropical and subtropical areas of the world, has been used traditionally throughout the world for many kinds of wound healing treatments as well as remedies for asthma, sore throats, constipation, elephantiasis, snakebite, bleeding, and worm infections [1,19]. Secondary metabolites include sterols (Ponasterone, Pterosterone, Campesterol, stigmasterol, etc), flavonoids (Quercetin-3-O-β-D-glucoside, Quercetin-3-O-α-Lrhamnoside, Quercetin-3-O-α-Lrhamnosyl-7-O-β-D-glucoside, Kaempferol, Quercetin), terpenoids ((2S,3S)-Pterosin C, (2R)-Pterosin P, (2S,3S)-Sulphated pterosin C, etc), triterpenoids (Taraxerol, β-amyrin, Germanicol, Lupenone, Betulin, Lupeol, α-amyrin, Phytol, Squalene, etc) alkaloids, glycosides, saponins, tannins, and phthalates have been identified in *A. aureum* [20]. Numerous extracts and phytochemicals from *A. aureum* have powerful anti-inflammatory, ulcer-healing, tyrosinase-inhibiting, analgesic, anti-tumor, anti-fertility, anti-cancer, antibacterial, antiviral, and wound-healing properties, based on *in-vitro* and *in-vivo* studies [20].

Aegiceras corniculatum (L.) Blanco

The mangrove tree or shrub *Aegiceras corniculatum* Figure 1(3), locally known as 'Pookkandal' or 'Karinjikkata', is a black mangrove/river mangrove of the Primulaceae plant family, and is used in traditional medicine to treat diabetes and inflammation [1]. The fruits are edible, and are consumed in many communities in various ways according to their local traditions [21]. This species provided numerous hydroquinones, saponins, and triterpenes that were all isolated, and it was shown that each of these isolated chemicals had distinct pharmacological effects. Nine compounds were reported by [22] include falcarindiol, resveratrol anthraquinone derivatives, quercetin lupeol, then, six compounds were reported by [23] includes aegicornin, 5-O-methylembelin, stigmasterol, α-spinosterol, fucosterol, palmitic acid, and another seven compounds, namely, 2-methoxy-3-nonylresorcinol, 3,7-dihydroxy-2, 5-diundecylnaphthoquinone, 5-O-ethylembelin, 2-O-acetyl-5-O-methylembelin, 2,7-dihydroxy-8-methoxy-3,6-diundecyldibenzofuran-1,4-dione, 10-hydroxy-4-O-methyl-2,11-diundecylgomphilactone, and 2,8-dihydroxy-7-methoxy-3,9-diundecyldibenzofuran-1,4-dione by [24]. A saponin from this species strongly promoted apoptosis of B16F10 melanoma cells and *A. corniculatum* could be potential candidates for treating cancer and inflammatory illnesses [25].

Avicennia marina (Forssk.) Vierh

This species is a grey mangrove, which is a member of the Acanthaceae plant family, is renowned for being an immense source of medicinal benefits. Both traditional and modern medicine utilise every component of this species [26], and is locally known as 'Chakkappoo' Figure 1(5) or 'Cheru-uppatti'. The tender leaves, the fruits, seeds and seedlings of *A. marina* are globally used as a vegetable [1]. Chocolate made from the fruit of *A. marina* has a patent, and this mangrove fruit is being explored as functional food in Mid-

dle East, where this species is a dominant one [27]. *A. marina* stores different chemical compounds, including cyclic triterpenoids, flavonoids, alkaloids, iridoids, polyphenols, naphthoquinones, polysaccharides, and steroids, most of them displaying potent antitumor activity. Avicennone A, stenocarpoquinone B, avicequinone C, avicenol A, avicenol C, and a mixture of Avicennone D and E were used to demonstrate an anti-proliferative effect on K562 human chronic myeloid leukaemia cells and L-929 mouse fibroblasts as well as cytotoxic activity against the HeLa human cervix carcinoma cell line [28]. Some commonly found flavones- quercetin and kaemferol, naphthoquinones-avicennone A–G, terpenoids -betulin and lupeol, etc are present in this species. An alkaloid, phenobarbitone from the bark of *A. marina* has been reported [29]. Trans-β-ocimene, 2,3-butanediol, α-farnesene, and 3-hydroxy-2-butanol contribute to the flowery scent of this species [30].

Avicennia officinalis L

Avicenna officinalis, is a common white mangrove plant in Kerala, and is locally referred as 'uppatti'. It is an Acanthaceae family plant with pneumatophores that range in length from 8 to 20cm and grow to heights of 12 to 18 metres. The famous Arab physician Ibn-Sina (Avicenna) is credited with giving this plant its name, and it is also known by the herbal name "Tumbara Vrishka" because its yellow blossoms Figure 1(2) are rich in honey. All of the plant's parts have traditionally been used to treat bacterial, fungal, and viral infections as well as cancer, rheumatism, dysentery, ulcers, Alzheimer's, and dysentery, and its fruits, and seeds as vegetables [1]. *A. officinalis* studies highlights that it contains chemical compounds like alkaloids, flavonoids, triterpenes, phenols, glycosides, saponin, and tannins, and it also highlights that it is used as an antioxidant, anti-fungal, anti-microbial, anti-inflammatory, antiviral, antidiuretic, neuropharmacological, antiviral, antidiabetic and anticancer agent [31]. There have been reports of the triterpenoids α-amyrin, β-amyrin, lupeol, oleanolic acid, and ursolic acid from this plant, as well as the regularly occurring sterols cholesterol, campesterol, stigmasterol, sitosterol, and stigmast-7-en-3-ol [32]. Additionally reported compounds include araviridoid, coumaroyl mussaenosidic acid, velutin, -tocopherol, and quinone derivatives [33].

Bruguiera cylindrica (L.) blume

The large-leafed orange mangrove *Bruguiera cylindrica* of the Rhizophoraceae family, commonly known as "Kuttikandal" or "Cherukandal," grows a height up to 20m and bears pneumatophore roots. A cluster of two to five greenish-white flowers on this plant blooms, and it produces edible fruits Figure 1(4) that are 15cm long and have a curved cylinder shape [21]. The local inhabitants of India have traditionally utilised the bark of *B. cylindrica* to heal ulcers and haemorrhages [16], and its leaves as a substitute for tea [1]. The *B. cylindrica* extracts were found to be a rich source of several phytochemicals, including anthraquinone, terpenoids, flavonoids, saponins, phenolics, and alkaloids, and its antibacterial activity was supported by terpenoid, which was specifically founded in leaves and twigs [17]. Betulin, Ursolic acid, Tropins, Luteolin, Kaempferol, Apigenin, Oleic acid, Feruloyltaraxerols, and Coumaroyltaraxerols are a few of the compounds with reported therapeutic potential from this species [34,35].

Kandelia candel (L.) druce

Kandelia candel, a species of white mangrove belonging to the plant family Rhizophoraceae, is referred to locally as "Ezhuthanikandal" or "Cherukandal," and it has been used traditionally to treat diabetes [21]. According to claims, the fruits of the *K. candel* are a good source of tannins and ascorbic acid [36], and they also have a high level of antioxidant activity [37]. The fruits contain starch and can be used to produce wonderful cakes or sweetened stuffing for pastries [1]. Chemical profile of this species reveals the presence of compounds including one sesquiterpene glycoside-kandelside, three megastigman glycoside compounds-blumenol C glucoside, (3R,9S)-megastigman-5-ene-3,9-diol 3-O-b-D-glucopyranoside, corchoionoside C, and fifteen phenolic compounds- protocatechuic acid, caffeic acid, chlorogenic acid, threo and erythro-1-C-syringyl-glycerol, syringaresinol-b-D glucoside, isorhamnetin 3-O-[a-rhamnopyranosyl-(1-6)-b-glucopyranoside], isorhamnetin 3-O-b-D-glucopyranoside, kaempferol 3-neohesperidoside, quercetin-3-O-glucoside, quercetin-3-O-rutinoside, cathechin, epicatechin, engeletin, and kaemferol-3-O-rhamnoside [38]. The compounds threo and erythro-1-C-syringyl-glycerol, as well as corchoionoside C, have an inhibitory effect on the production of pro-inflammatory cytokines in bone marrow-derived dendritic cells (BMDCs) [38]. Because it releases the two-nitrogen floral scent chemicals indole and methyl anthranilate, this plant attracts pollinators [30].

Rhizophora apiculata blume

Rhizophora apiculata is a species of red mangrove type that belongs to the Rhizophoraceae family and is locally known as 'Vallikkandal' found in a number of tropical countries. It has traditionally been utilised as an antiseptic, astringent [1], and to control bleeding in fresh wounds, hepatitis, and to treat chronic typhoid fever

[39]. The antioxidant, anti-tyrosinase, and anti-quorum sensing properties of *R. mucronata* have been claimed to support its application as a substitute for tea [40,41], and its nutritionally rich fruit as a vegetable [21]. *R. apiculata* covered a spectrum of biological activities, and its phytochemical screenings confirming the presence of β-amyrin, triacantanol, taraxeryl cis-p-hydroxycinnamate, careaborin, β-sitosterol, kaempferol, gallic acid, rutin, quercetin, β-amyrone, ascorbic acid, and taraxerol as components [39]. The pyroligneous acid of *R. apiculata* included the three antioxidant chemicals, 3-methoxyphenol, catechol, and syringol, which had distinctly different capacities to scavenge DPPH radicals and ABTS radical cations as well as reduce ferric and molybdenum (VI) ions [42]. The compounds found in the methanolic extract of *R. apiculata* included 4-pyrrolidinyl, pyrazole, ketone derivatives, and thiazolidine-diones, which have been relevant for the anti-inflammatory and anti-tumor action against B16F10 melanoma cells in mouse models [12]. By suppressing the expression, a polysaccharide from the leaves of *R. apiculata* was effective against in humans and simian immunodeficiency viruses- HIV-1, HIV-2, and SIV [43].

Rhizophora mucronata Poir

Red mangrove, *Rhizophora mucronata*, which grows up to a height of 20-25 metres like a banyan tree and is locally referred as 'Panachikandal' or 'Peakandal', is a member of the Rhizophoraceae family. Reports have shown that they are very effective against diabetes, haemorrhage, hepatitis, elephantiasis, febrifuge, malaria and ulcer [1,44]; and this plant are rich in therapeutic chemicals that would support the advancement of medical research against many ailments [45]. *R. mucronata* has been proposed as a tea alternative [40], and this has been supported by its antioxidant, anti-tyrosinase, and anti-quorum sensing features [41]. These species contain a lot of phenolic compounds including catechin, which have strong anti-inflammatory and anti-cholinesterase effects [46]. The chloroform extract of *R. mucronata* showed two oleanene pentacyclic triterpenoids with potential anti-inflammatory and antioxidant properties [47]. The beyerane diterpenoids, Rhizophorins A-E, were found in abundance in the ethyl acetate extract of *R. mucronate* [48-50]. From the leaves of *R. mucronata*, the two bioactive triterpenoids betulin and lupeol [51], as well as its antimalarial effectiveness against *Plasmodium falciparum* [11], have been observed. The chemical analysis of the root bark of *R. mucronata* confirmed the presence of xanthones along with α-amyrin, β-amyrin, atranorin, Palmitone, dimyristyl ketone, β-sitosterol, and - sitosterol glucoside [52]. The bark of *R.mucronata* shows potential efficacy against the NDV-Newcastle disease virus, VV-vaccinia virus, EMCV-encephalomyocarditis virus, SFV-Semliki Forest virus, and HBV- Hepatitis B surface antigen -HBsAg Virus [53]. The traditional drink kombucha herbal, made from the mangrove fruit *R. mucronata*, had antidiabetic and antioxidant effects by inhibiting -glucosidase [54]. The ripen fruit of *R. mucronata* is consumed by mangrove societies because it contains plenty of flavonoid, steroids, tannins, and essential minerals as well as its variety of health benefits, including antiviral, anti-inflammatory, antibacterial, antioxidative, antidiabetic, and antitumor properties [55].

Sonneratia alba Sm

True mangrove *Sonneratia alba* from the family of Lythraceae is also known as "nakshathra kandal," which is a rare species inKerala [18]. In addition to being consumed as vegetables, the mangrove communities also used it as a home remedy for sprains, skin problems, malaria, and swellings [1,44]. It is a potent source of phenolics, flavonoids, steroids, triterpenoids, and tannin, and the major compounds reported are oleanolic acid, betulin, betulinic acid, alphitolic acid, methyl gallate, and 5hydroxymethylfurfural [56]. The antibacterial active lupane-type triterpenoids namely lupeol, lupan-3-β-ol, and 3β-hydroxy-lup-9(11),12–diene-28-oic acid, are also reported from the bark of *S. alba* [57]. Specifically, trans β-ocimene, 2-heptanone, 2,4-dithiapentane, and methyl-2-methylbutanoate constitute the flowery scent of *S. alba* [30].

Sonneratia caseolaris (L.) Engl

Belonging to the Lythraceae plant family, *Sonneratia caseolaris* (White/milkwood mangrove) can grow up to 20 meters in height and are locally known as 'Chakkara-kandal', 'Apple-kandal' or 'Blathi-kandal' Figure 1(6). It is reported that *S. caseolaris* was traditionally used as an astringent and antiseptic, sprain poultices, in skin cosmetics, in treating piles, and in arresting haemorrhage (Bandaranayake, 1998). The *S. caseolaris* plants are abundant in phenolic compounds, alkaloids, flavonoids, tannins, and the pectin-rich fruit that is used to make vegetable and fruit drinks [1,21]. Some of the chemical compounds reported from this species include those in steroids, triterpenoids, flavonoids and carboxylic derivatives categories such as β-sitosterol, stigmasterol, β-sitosterol palmitate, β-daucosterol, betulin, lupeol, oleanolic acid, ursolic acid, ellagic acid derivatives, (+)-dihydrokaempferol, luteolin, quercetin-3-O-β-L-arabinopyranoside, and methyl gallate [58]. The flavonoid of this species, luteolin also exhibits an *in-vitro* cytotoxicity against SMMC-7721 human hepatoma cells. Two fla-

vonoids from the leaves, luteolin and luteolin 7-O-glucoside, have been shown to have DPPH radical scavenging activity [59]. Reports on this species' chemical constituents as well as its usage in treating liver and skin conditions have increased its popularity in the group of Indian medicinal plants.

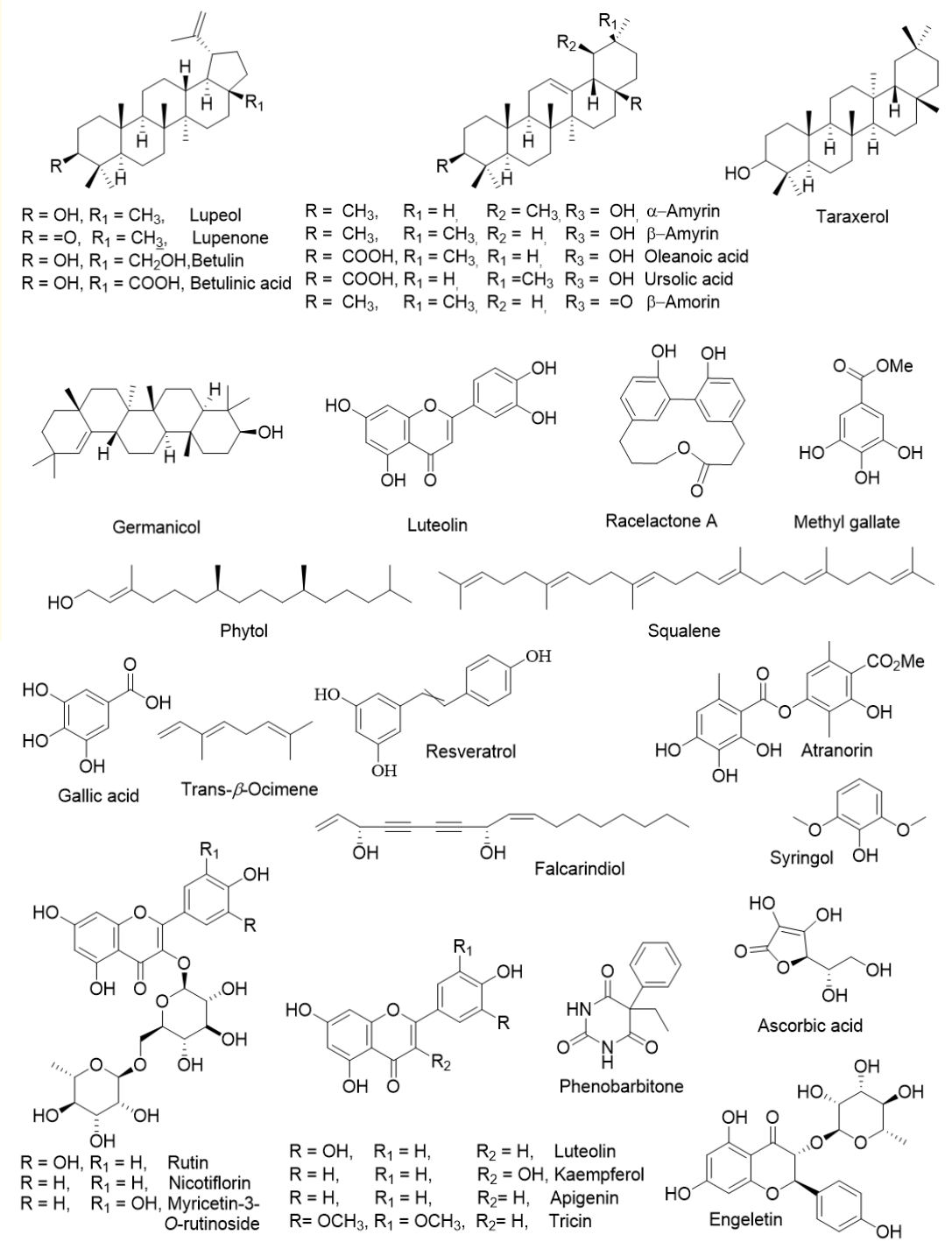

Figure 2: Some of the Bioactive Compounds of Mangroves found in Kerala Coast.

Conclusion

Management and conservation of mangroves has become a global topic of discussion today. In addition to the natural uses of mangroves, it has been traditionally and scientifically proven that each mangrove plant is a storehouse of medicinal properties. Therefore, it is essential to preserve the mangroves for the benefit of mankind while maintaining the natural habitat and to plant more endangered species. Even while several Asian countries have long used traditional foods made from edible mangroves, Kerala, Indian state, notably has little knowledge of the mangroves' potential as a food source. Given their abundance in phytochemicals and potential for advancement as processed foods, numerous mangroves definitely exhibit significant potency in the development of functional foods. Mangrove plants can be used for exploiting their chemical characteristics for medicinal and nutritional purposes quite effectively, as have been proven by numerous research studies. As soon as we succeed in convincing society that mangrove forests are also a source of food and medicine in addition to their capacity to purify water, protect coastlines, absorb carbon dioxide, and release a lot of oxygen, then everyone will be responsible for preserving this naturally occurring bio-medicinal ecosystem.

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