Metabolites and bioactivities of Rhizophoraceae mangroves

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Abstract: This review examines the chemical compositions and bioactivities of mangrove plants belonging to the Rhizophoraceae family. The Rhizophoraceae family of true mangrove plants is the most common and is also widely distributed species. It consists of 24 species across four genera. Of the 24 species, 12 species remain unexamined for their phytochemical constituents. There have been 268 metabolites reported from 16 species. The key phytochemical constituents identified across the family are the diterpenoids and triterpenoids. The major diterpenoids include pimaranes, beyeranes, kaurenes, dolabranes and labdanes whereas the significant triterpenoids are lupanes, dammaranes and oleananes. Disulphides, dolabranes and labdanes are considered to be the chemotaxonomic markers of the genera Bruguiera, Ceriops and Rhizophora respectively.

Keywords: Rhizophoraceae, Bruguiera, Rhizophora, terpenoids, Ceriops

Introduction
Mangrove plants are potential sources of biologically active chemicals that are discernible from their wide spread application in ethnopharmaceutical practices. Their habitat exists under stressful conditions and serve as a bridging ecosystem between freshwater and marine systems. These plants have specially adapted their own morphological structures and physiological mechanisms to their harsh natural surroundings. Pneumatophores, stilt roots and buttresses, with salt-excreting glands found in their leaves, and viviparous propagules are some of the several highly specialized adaptations of this group. The path of photosynthesis in mangroves is different from other glycophytes. Furthermore, there are alterations in other physiological processes such as carbohydrate metabolism or polyphenol synthesis. These plants survive under extreme conditions of salinity, temperature gradients, tidal fluctuations and anoxic soil conditions, with these plants possessing many chemical compounds, which protect them from these destructive elements. Even though extracts from mangroves and mangrove-dependent species possess therapeutic activity against humans, animal and plant pathogens, the specific metabolites responsible for these bioactivities remains to be elucidated.

1 Rhizophoraceae
The global mangrove plant have 84 species belonging to 24 genera and 16 families. Among them, 70 species are true mangroves pertaining to sixteen genera and eleven families whereas fourteen species are semi mangroves belonging to eight genera and five families. According to Wu et. al, suggests the family Rhizophoraceae belongs to true mangrove family, which contains 21 species in four genera. In contrast three more species; Rhizophora annamalayana, Kandelia obovata and Ceriops zeppeilana blume become 24 species in four genera in the Rhizophoraceae family of true mangroves. Thus the family Rhizophoraceae include: Bruguiera which contains seven species, Ceriops (five species), Kandelia (two species) and Rhizophora (ten species). The distribution of species in Rhizophoraceae family is detailed in Table 1. 54 studies can achieve the validity of ethnomedicines as well as apply the use of mangrove plants in the development of new drugs.

In this review, the compounds identified from this family were listed, and their reported biological activities were compiled. Also chemotaxonamy and importance of further phytochemical research is discussed.

2 Chemical Constituents
2.1 Bruguiera: The genus Bruguiera has six species and one hybrid species which are derived from B. sexangula, including B. cylindrica, B. exarista, B. gymnorrhiza, B. hainessi, B. parviflora, B. sexangula and B. sexangula var.
Table 1. Mangroves of Rhizophoraceae family of true mangroves

| Bruguiera | Ceriops | Kandelia | Rhizophora |
|-----------|---------|----------|------------|
| B. cylindrica | C. decandra | K. candel | R. apiculata |
| B. exaristata | C. tagal | K. obovata | R. harrissoni |
| B. gymnorrhiza | C. tagal var. australasia | R. lamarkii |
| B. hainessii | C. tagal var. typical | R. mangle |
| B. parviflora | C. zeppeliana blume | R. muconata |
| B. sexangula | R. racemosa |
| B. sexangula var. rhynchopetala | R. samoessis |
| | R. selala |
| | R. stylosa |
| | R. annamalayana |

**rhynchopetala.** The metabolic pattern of this genus has been extensively characterised by a suite of diterpenes and triterpenes. In addition, these species also produce flavonoids, tropane derivatives and cyclic polysulphides. These include 22 metabolites from *B. cylindrica*, 54 metabolites from *B. gymnorrhiza*, nine metabolites from *B. exaristata*, six metabolites from *B. parviflora*, two metabolites from *B. sexangula* and 40 metabolites from *B. sexangula var. rhynchopetala* were identified so far. A total of 114 metabolites have been reported form this genus including. A detailed list of chemical compounds identified from *Bruguiera* is recorded in Table 2.

Three sulphur compounds along with an alkaloid brugine were reported from the stem and bark of *B. cylindrica* by Japanese scientists of during 1975–1976. 20 years later, a number of oleananes and lupanes (triterpenoids) and one kaurane (diterpenoid) were reported. The first report on the chemical constituents of *B. gymnorrhiza* dates back to 1978 in which Sarkar and Ganguly reported a new triterpenoid called gymnorrhizol (3-epi-δ-amyrin). Since then various triterpenoids (oleananes, oleananes, ursanes, dammaranes) and diterpenoids (kauranes, pimaranes, beyaranes) along with sulphur compounds, sterols and aromatic compounds were reported from this plant.

Only two reports are available regarding the chemical constituents of *B. exaristata*. As part of their investigation on tumor inhibitory plants, in 1969 Loder and Russell identified the presence of alkaloids (brugine, tropine and tropine esters of acetic, isobutyric, isovaleric, propionic, n-butyric and benzoic acids) in the bark extracts of *B. exaristata* while a pronounced accumulation of 1-d-1-O-methyl-muco-inositol in the young leaves of *B. exaristata* was reported later by Richter and his team.37

In a continuing search for bioactive constituents from Thai medicinal plants, Chunnkaw and his team isolated and elucidated a new triterpenoid ester 3-(Z)-caffeoyllypeol along with five other triterpenoids; lupeol caffeate, 3-(Z)-coumaroyllypeol, dioslupecin A, lupeol and lupenone from the fruits of *B. Parviflora*. The earliest work regarding the chemical constituens of mangroves deals with the isolation and characterization of the tropine 1,2-dithiolate-3-carboxylate named as brugine from the stem bark of *B. sexangula*. Later the same team identified additional alkaloids from the same plant as part of their investigation on tumor inhibitory plants. In a study focusing on the marine fauna and flora from Chinese coasts, Li and his coworkers collected samples of the mangrove *B. sexangula* from Hainan Province, China. On separation of an EtOAc-soluble fraction of a methanol extract of the title plant, they isolated a new triterpene, named sexangulic acid.

Investigation of Chinese mangrove plants led to the isolation and characterisation of 13 compounds; three new diterpenes; six known diterpenes, a new dithiobenzoquinone two cyclic disulfides and 2,6-dimethoxy-1,4-benzoquinone from the EtOH extract of the stem of *B. sexangula var. rhynchopetala*. Further several triterpenoids and sterols were reported.25 Recently, a continuous investigation for chemical diversity of *B. sexangula var. rhynchopetala* led to the isolation and characterization of six new phenolic constituents named rhynocosides A–F, together with twelve known compounds including two phenolic glycosides, four flavonoids, and six lignan derivatives.

| Alkaloids |
|-----------|
| 1 R = H |
| 2 R = Me |
| 3 R = Ph |
| 4 R = CH(CH3)2 |
| 5 R = CH2CH(CH3)2 |
| 6 R = CH3CH2CH(CH3)2 |
| 7 R = CH3CH2CH2OCH3 |
| 8 R = CH3CH2OCH3 |

**Figure 1.** Alkaloids from Rhizophoraceae mangroves

2.2 Ceriops: The genus of *Ceriops* has two species and two varieties, namely *C. tagal* (Perr.), *C. decandra*, *C. tagal var. australasia* and *C. tagal var. typical*. Typical. These plants are valued for their rich tannin content and are a rich source of pentacyclic triterpenoids. To date, 30 metabolites from *C. decandra* and 72 metabolites from *C. tagal* are known. Thus a total of 92 metabolites including 45 diterpenoids (23 dolabranes, six dimeric diterpenes, four beyeranes, five kauranes, and seven pimaranes) and 45 triterpenoids (35 lupanes, seven dammaranes, one oleanane, one ursane, and one abietane) along with two steroids have been reported so far from this genus.

On examination of the roots of *C. decandra* collected from the Kauvery estuary (Parangipettai coast), Anjaneyulu and his team isolated and characterised twelve diterpenoids. Subsequently, two novel triterpene esters were isolated from the leaves of *C. decandra* in addition to 16 known triterpenes.
by scientists from Thailand. Dolabranes (diterpenoids) are the marker metabolites of *C. tagal*. These compounds can be used as chemotaxonomic markers of this plant. Dimeric diterpenoids (tetraterpenoids) and triterpenoids of lupane, dammarane, pimarane groups are also found in this plant. One abietane and an oleanane triterpenoid were also isolated from the stems and twigs of *C. tagal*. The chemical constituents identified from *ceriops* are listed in Table 3.

| Table 2. Chemical constituents from the genus *Bruguiera* |
|-------------------------------|-------------------|----------------|-------------|
| Compound Class and Name       | Plant             | Plant Part     | References  |
| Alkaloids                     |                   |                |             |
| brugine (1)                   | *B. cylindrica*    | stem and bark  | 14          |
| tropine (2)                   | *B. exaristata*    | stem bark      | 6           |
| tropine acetate (3)           | *B. sexangula*     | stem bark      | 6           |
| tropine benzoate (4)          | *B. sexangula*     | stem bark      | 6           |
| tropine isobutyrate (5)       | *B. sexangula*     | stem bark      | 6           |
| tropine isovalerate (6)       | *B. sexangula*     | stem bark      | 6           |
| tropine n-butyrate (7)        | *B. sexangula*     | stem bark      | 6           |
| tropine propionate (8)        | *B. sexangula*     | stem bark      | 6           |
| **D-Friedooleananes** (Triterpenoids)** |                   |                |             |
| 3α-taraxerol (9)              | *B. cylindrica*    | fruits         | 15          |
| 3α-E-caffeoyltaraxerol (10)   | *B. cylindrica*    | fruits and hypocotyls | 16 |
| 3α-E-coumaroyltaraxerol (11)  | *B. cylindrica*    | fruits         | 15          |
| 3α-E-feruloyltaraxerol (12)   | *B. cylindrica*    | fruits         | 15          |
| 3α-Z-coumaroyltaraxerol (13)  | *B. cylindrica*    | fruits         | 15          |
| 3α-Z-feruloyltaraxerol (14)   | *B. cylindrica*    | fruits         | 15          |
| 3β-taraxerol (26)             | *B. cylindrica*    | fruits         | 15          |
| 3β-E-feruloyltaraxerol (17)   | *B. cylindrica*    | fruits         | 15          |
| 3β-Z-feruloyltaraxerol (23)   | *B. cylindrica*    | fruits         | 15          |
| taraxerone (25)               | *B. sexangula var. rhynchopetala* | stem         | 12          |
| **Lupanes** (Triterpenoids)   |                   |                |             |
| 3α-lupenol (32)               | *B. cylindrica*    | fruits and hypocotyls | 16 |
| 3α-E-coumaroyllupenol (34)    | *B. cylindrica*    | fruits and hypocotyls | 16 |
| 3α-Z-coumaroyllupenol (37)    | *B. cylindrica*    | fruits and hypocotyls | 16 |
| 3β-E-caffeoyllupenol B (44)   | *B. cylindrica*    | fruits and hypocotyls | 16 |
| 3β-Z-caffeoyllupenol (38)     | *B. parviflora*    | fruits         | 8           |
| 3β-E-coumaroyllupenol (45)    | *B. cylindrica*    | fruits and hypocotyls | 16 |
| 3β-Z-coumaroyllupenol (55)    | *B. cylindrica*    | fruits and hypocotyls | 16 |
| betulin (57)                  | *B. gymnorrhiza*   | leaves         | 17          |
| lupenone (64)                 | *B. cylindrica*    | fruits and hypocotyls | 16 |
|                             | *B. sexangula var. rhynchopetala* | stem         | 12          |
|                             | *B. parviflora*    | fruits         | 8           |
| lupeol (65)                   | *B. cylindrica*    | fruits and hypocotyls | 16 |
|                             | *B. gymnorrhiza*   | leaves         | 17          |
|                             | *B. sexangula var. rhynchopetala* | stem         | 12          |
|                             | *B. parviflora*    | fruits         | 8           |
| trans-hydroxy-cinnamoyl lupeol (66) | *B. sexangula var. rhynchopetala* | stem         | 12          |
| dioslupecin A (57)            | *B. parviflora*    | fruits         | 8           |

**Oleanane** (Triterpenoids)
| Chemical Name                  | Plant Part/Species          | Quantity |
|-------------------------------|-----------------------------|----------|
| Oleanolic acid (70)           | B. gymnorrhiza leaves       | 17       |
| β-amyrin (71)                 | B. gymnorrhiza leaves       | 17       |
| β-amyril palmitate (72)       | B. sexangula var. rhynchopetala stem | 12       |
| **Ursanes (Triterpenoids)**   |                             |          |
| Ursolic acid (73)             | B. gymnorrhiza leaves       | 17       |
| α-amyrin (74)                 | B. gymnorrhiza leaves       | 17       |
| **Dammaranes (Triterpenoids)**|                             |          |
| Bruguierin A (75)             | B. gymnorrhiza flowers      | 18       |
| Bruguierin B (76)             | B. gymnorrhiza flowers      | 18       |
| Bruguierin C (77)             | B. gymnorrhiza flowers      | 18       |
| **Triterpene alcohol**        |                             |          |
| Gymnorrhizol (3-epi-δ-amyrin) (85) | B. gymnorrhiza leaves | 19       |
| **Lanostanes (Triterpenoids)**|                             |          |
| Squalene (86)                 | B. sexangula stem           | 10       |
| **Squalene (Triterpenoid)**   | B. sexangula var. rhynchopetala stem | 12       |
| **Fatty acids**               |                             |          |
| Linoleic acid (88)            | B. gymnorrhiza leaves       | 20       |
| Linolenic acid (89)           | B. gymnorrhiza leaves       | 20       |
| Palmitic acid (90)            | B. gymnorrhiza leaves       | 20       |
| **Steroids**                  |                             |          |
| 3-O-α-L-rhamnopyranosyl-(+)-catechin-(4α→2)phloroglucinol (91) | B. gymnorrhiza bark | 21       |
| Campesterol (92)              | B. gymnorrhiza leaves       | 17       |
| Cholesterol (93)              | B. gymnorrhiza leaves       | 17       |
| Daucosterol (94)              | B. sexangula var. rhynchopetala stem | 12       |
| β-sitosterol (96)             | B. sexangula var. rhynchopetala stem | 12       |
| Stigmasterol (99)             | B. gymnorrhiza leaves       | 17       |
| α-hydroxy-sitosterol (100)    | B. sexangula var. rhynchopetala stem | 12       |
| **Kauranes (Diterpenoids)**   |                             |          |
| (16R)-13,17-epoxy-16-hydroxy-ent-kaur-9(11)-en-19-ol (101) | B. sexangula var. rhynchopetala stem | 11       |
| 13,16,17-trihydroxy-ent-9(11)-kaurene-19-oic acid (102) | B. gymnorrhiza stem | 22       |
| 13-hydroxy-16-ent-kauren-19-al (103) | B. gymnorrhiza stem | 22       |
| 16,17-dihydroxy-ent-9(11)-kaurene-19-al (107) | B. gymnorrhiza stem | 23       |
| 16,17-dihydroxy-ent-9(11)-kauren-19-oic acid (108) | B. sexangula var. rhynchopetala stem | 11       |
| 16,17-dihydroxy-19-nor-ent-kaur-9(11)-en-3-one (109) | B. sexangula var. rhynchopetala stem | 11       |
| 16-ent-kauren-13,19-diol (115) | B. gymnorrhiza stem | 22       |
| 16-ent-kauren-19-ol (110)      | B. gymnorrhiza bark         | 23       |
| 16H-17,19-ent-kauranediol (104) | B. gymnorrhiza stem | 22       |
| 16H-17-hydroxy-ent-kauren-19-oic acid (105) | B. gymnorrhiza stem | 22       |
| 16,17-dihydroxy-ent-kauren-19-al (106) | B. gymnorrhiza stem | 22       |
| 17-chloro-13,16-dihydroxy-ent-kauren-19-al (111) | B. gymnorrhiza stem | 22       |
| Ceriopsin F (113)             | B. sexangula var. rhynchopetala stem | 11       |
| Steviol (120)                 | B. gymnorrhiza bark         | 23       |
| Molecular Formula | Plant | Part of Plant | Source |
|-------------------|-------|---------------|--------|
| methyl(16R)-13,17-epoxy-16-hydroxy-ent-kaur-9(11)-en-19-oate (119) | B. sexangula var. rhynchopetala | stem | 11 |
| methyl-16α,17-dihydroxy-ent-kaur-9(11)-en-19-oate (116) | B. gymnorrhiza | bark | 23 |
| methyl-16,17-dihydroxy-ent-kauran-19-oate (117) | B. gymnorrhiza | stem | 22 |
| B. gymnorrhiza stem 11 | |
| B. gymnorrhiza bark 23 | |
| B. sexangula var. rhynchopetala stem 11 | |
| B. gymnorrhiza stem 22 | |
| Pimaranes (Diterpenoids) | |
| 15(S)-isopimar-7-en-15,16-diol (123) | B. gymnorrhiza | stem | 25 |
| ent-8(14)-pimarene-15R,16-diol (128) | B. gymnorrhiza | root bark | 23 |
| ent-8(14)-pimarene-1α,15R,16-triol (129) | B. gymnorrhiza | stem | 25 |
| isopimar-7-en-1β,15R,16-triol (130) | B. gymnorrhiza | stem | 25 |
| (5R,9S,10R,13S,15S)-ent-8(14)-pimarene-1-oxo-15R,16-diol (122) | B. gymnorrhiza | stem | 25 |
| (1H,15R)-ent-pimar-8(14)-ene-1,15,16-triol (130) | B. sexangula var. rhynchopetala | stem | 11 |
| Beyeranes (Diterpenoids) | |
| (4R,5S,5R,9R,10S,13S)-ent-17-hydroxy-16-oxobeyeran-19-al (135) | B. gymnorrhiza | stem | 22 |
| ent-17-hydroxy-16-oxobeyer-9(11)-en-19-al (136) | B. sexangula var. rhynchopetala | stem | 11 |
| Sulphur compounds | |
| 4-hydroxy-1,2-dithiolane (144) | B. cylindrica | stem and bark | 14 |
| brugierol (145) | B. cylindrica | stem and bark | 14 |
| | B. gymnorrhiza | flowers, leaves and stem | 26, 27 |
| bruguiesulfurol (146) | B. sexangula var. rhynchopetala | stem | 11 |
| | B. gymnorrhiza | Flowers, leaves and stem | 26, 27 |
| cis-3,30-dihydroxy-1,5,10,50-tetrathiacyclodecane (147) | B. gymnorrhiza | leaves and stem | 27 |
| gymnorrhizol (148) | B. gymnorrhiza | leaves and stem | 27 |
| isobrugierol (149) | B. cylindrica | stem and bark | 14 |
| | B. gymnorrhiza | flowers and leaves and stem | 26, 27 |
| neogymnorrhizol (150) | B. sexangula var. rhynchopetala | stem | 11 |
| trans-3,30-dihydroxy-1,5,10,50-tetrathiacyclodecane (151) | B. gymnorrhiza | leaves and stem | 27 |
| (–)-3,4-dihydro-3-hydroxy-7-methoxy-2H-1,5-benzodithiepine-6,9-dione (152) | B. sexangula var. rhynchopetala | stem | 11 |
| Aromatic compounds | |
| 1-(3-hydroxyphenyl)-hexane-2,5-diol (153) | B. gymnorrhiza | stem | 28 |
| 2,3-dimethoxy-5-propylphenol (154) | B. gymnorrhiza | branch | 29 |
| 3-(3-hydroxybutyl)-1,1-dimethylisochroman-6,8-diol (155) | B. gymnorrhiza | stem | 28 |
| brugierol A (156) | B. gymnorrhiza | stem | 28 |
| brugierol B (157) | B. gymnorrhiza | stem | 28 |
| brugierol C (158) | B. gymnorrhiza | stem | 28 |
| brugierol D (159) | B. gymnorrhiza | branch | 29 |
| Carbohydrates | |
| 1-d-1-O-methyl muco inositiol (161) | B. exaristata | leaves | 7 |
| Phenolic glycosides | |
| 2,6-dimethoxy-1,4-benzoquinone (162) | B. sexangula var. rhynchopetala | stem | 11 |

**Beyeranes (Diterpenoids)**

(4R,5S,5R,9R,10S,13S)-ent-17-hydroxy-16-oxobeyeran-19-al (135)

**Sulphur compounds**

4-hydroxy-1,2-dithiolane (144)

brogierol (145)

bruguiesulfurol (146)

cis-3,30-dihydroxy-1,5,10,50-tetrathiacyclodecane (147)

gymnorrhizol (148)

isobrugierol (149)

**neogymnorrhizol (150)**

**trans-3,30-dihydroxy-1,5,10,50-tetrathiacyclodecane (151)**

(–)-3,4-dihydro-3-hydroxy-7-methoxy-2H-1,5-benzodithiepine-6,9-dione (152)

**Aromatic compounds**

1-(3-hydroxyphenyl)-hexane-2,5-diol (153)

2,3-dimethoxy-5-propylphenol (154)

3-(3-hydroxybutyl)-1,1-dimethylisochroman-6,8-diol (155)

**Carbohydrates**

1-d-1-O-methyl muco inositiol (161)

**Phenolic glycosides**

2,6-dimethoxy-1,4-benzoquinone (162)
| Compound Class and Name | Plant | Plant Part | References |
|-------------------------|-------|------------|------------|
| 1-[(α-L-rhamnopyranosyl-(1→6)-β-D-glucopyranosyloxy)-3,4,5-trimethoxybenzene (163)] | B. sexangula var. rhynchopetal | stem | 13 |
| 3,4,5-trimethoxyphenyl-β-D-glucopyranoside (164) | B. sexangula var. rhynchopetal | stem | 13 |
| rhynoside A (168) | B. sexangula var. rhynchopetal | stem | 13 |
| rhynoside B (169) | B. sexangula var. rhynchopetal | stem | 13 |
| rhynoside C (170) | B. sexangula var. rhynchopetal | stem | 13 |
| rhynoside D (171) | B. sexangula var. rhynchopetal | stem | 13 |
| Flavonoids | | | |
| myricetin-3-O-rutinoside (199) | B. sexangula var. rhynchopetal | stem | 13 |
| nicotiflorin (200) | B. sexangula var. rhynchopetal | stem | 13 |
| rutin (205) | B. sexangula var. rhynchopetal | stem | 13 |
| tricin (206) | B. sexangula var. rhynchopetal | stem | 13 |
| Lignans | | | |
| (+)-5′-methoxyisolariciresinol-9′-β-D-xylopyranoside (207) | B. sexangula var. rhynchopetal | stem | 13 |
| (+)-lyoniresinol-3α-O-α-L-rhamnopyranoside (208) | B. sexangula var. rhynchopetal | stem | 13 |
| brugunins A (209) | B. gymnorrhiza | branch | 29 |
| hedyotisols A (210) | B. sexangula var. rhynchopetal | stem | 13 |
| hedyotisols B (211) | B. sexangula var. rhynchopetal | stem | 13 |
| hedyotisols C (212) | B. sexangula var. rhynchopetal | stem | 13 |
| hedyotisols D (213) | B. sexangula var. rhynchopetal | stem | 13 |
| hedyotisols D (213) | B. sexangula var. rhynchopetal | stem | 13 |
| rhynoside E (214) | B. sexangula var. rhynchopetal | stem | 13 |
| rhynoside F (215) | B. sexangula var. rhynchopetal | stem | 13 |

Table 3. Chemical constituents of Ceriops
| Compounds                                                                 | Sources                  | Plant Parts                |
|--------------------------------------------------------------------------|--------------------------|----------------------------|
| (5S*,8S*,9S*,10S*,13S*)-2-hydroxy-16-nor-3-oxodolab-1,4(18)diene-15-oic    | C. tagal                 | stems and twigs            |
| acid (217)                                                               |                          |                            |
| (5S*,8S*,9S*,1R*,13S*)-dolab-3-ene-15-,16-diol                           | C. tagal                 | stems and twigs            |
| (220)                                                                   |                          |                            |
| (5S*,8S*,9S*,10R*,13S*)-dolab-4(18)-ene-15,16-diol                       | C. tagal                 | stems and twigs            |
| (216)                                                                   |                          |                            |
| erythroxydiol Y (222)                                                    | C. tagal                 | stems and twigs            |
| dolab-4(17),15(16)-dien-3-one                                            | C. tagal                 | roots                      |
| (238)                                                                   |                          |                            |
| 7-glycoloyl-2-hydroxy-1,4b,7,10a-tetramethyl-4a,4b,5,6,7,8,8a,9,10,10a-decahydrobenzen-3(4H)-one (239) | C. tagal                 | roots                      |
| Dimeri diterpenoids                                                      |                          |                            |
| tagalins I (244)                                                        | C. tagal                 | stems and twigs            |
|                          | C. tagal                 | roots                      |
| tagalins J (245)                                                        | C. tagal                 | stems and twigs            |
| tagalins L (241)                                                        | C. tagal                 | roots                      |
| tagalins M (242)                                                        | C. tagal                 | roots                      |
| tagalins N (243)                                                        | C. tagal                 | roots                      |
| 8(14)-enyl-pimar-2(3')-en-4(18')-ene-15(16-endolab-16,15,2,3'-oxoan-16-one (240) | C. tagal                 | roots                      |
| Beyranes (Diterpenoids)                                                  |                          |                            |
| ceropsin A (137)                                                        | C. tagal                 | roots                      |
| ceropsin B (138)                                                        | C. tagal                 | roots                      |
| criopsin G (139)                                                        | C. tagal                 | roots                      |
| isoviro (140)                                                           | C. tagal                 | roots                      |
| Auranes (Diterpenoids)                                                   |                          |                            |
| cerioprin E (112)                                                       | C. tagal                 | roots                      |
| cerioprin F (113)                                                       | C. tagal                 | roots                      |
| steviol (120)                                                           | C. tagal                 | roots                      |
| methyl-ent-16β,17-dihydroxy-9(11)-kauren-19-oate (118)                    | C. tagal                 | roots                      |
| ent-16β,17-dihydroxy-9(11)-kauren-19-oic acid (114)                      | C. decandra              | roots                      |
| Dammarane (Triterpenoids)                                                |                          |                            |
| cereotagalol A (78)                                                     | C. tagal                 | hypocotyls and fruits      |
| cereotagalol B (79)                                                     | C. tagal                 | hypocotyls and fruits      |
| cereotagalolperoxide (80)                                                | C. tagal                 | hypocotyls and fruits      |
| dammarenediol II (81)                                                    | C. tagal                 | hypocotyls and fruits      |
| fouquerol (82)                                                          | C. tagal                 | hypocotyls and fruits      |
| isofoquerol (83)                                                        | C. tagal                 | hypocotyls and fruits      |
| ocoitillo (84)                                                          | C. tagal                 | hypocotyls and fruits      |
| Oleananes (Triterpenoids)                                                |                          |                            |
| oleanolic acid (70)                                                     | C. tagal                 | hypocotyls and fruits      |
| ursane (Triterpenoid)                                                    | C. tagal                 | hypocotyls and fruits      |
| ursoic acid (73)                                                        | C. decandra              | leaves                     |
| Lupanes (Triterpenoids)                                                  |                          |                            |
| 28-hydroxyulup-20(29)-en-3-one (27)                                      | C. tagal                 | aerial parts               |
| 3-epi-betulin (28)                                                       | C. tagal                 | aerial parts               |
| 30-nor-lup-3β-ol-2-one (29)                                              | C. decandra              | aerial parts               |
| 3-epi-betulinic acid (30)                                                | C. tagal                 | aerial parts               |
| 3-oxo-lup-20(29)-en-28-oic acid (31)                                     | C. tagal                 | aerial parts               |
| 3a-betulinic acid (33)                                                   | C. decandra              | aerial parts               |
| 3a-O-trans-coumaroibetulinic acid (35)                                   | C. tagal                 | aerial parts               |
| Substance Description                                      | Source          | Part/Region     | References |
|------------------------------------------------------------|-----------------|-----------------|------------|
| 3α-O-trans-feruloylbetauninic acid (36)                    | C. tagal        | aerial parts    | 44         |
| 3β-E-cafeoyllupeol (44)                                    | C. decandra     | leaves          | 33         |
| 3β-O-cis-coumaroylbetulin (39)                            | C. tagal        | aerial parts    | 44         |
| 3β,20-dihydroxyxylene (40)                                | C. decandra     | leaves          | 33         |
| 3α-acetylbetauninic acid (41)                              | C. tagal        | hypocotyls and fruits | 43    |
| 3β-E-cafeoylbetulin (42)                                   | C. tagal        | hypocotyls and fruits | 43     |
| 3β-E-cafeoylbetauninic acid (43)                           | C. tagal        | hypocotyls and fruits | 43     |
| 3β-coumaroyllupeol (45)                                   | C. decandra     | leaves          | 33         |
| 3β-E-feruloylbetulin (46)                                  | C. decandra     | hypocotyls and fruits | 43     |
| 3β-E-feruloylbetulinic acid (47)                           | C. tagal        | hypocotyls and fruits | 43     |
| 3β-E-feruloyllupeol (48)                                   | C. decandra     | leaves          | 33         |
| 3β-hydroxylupan-29-oic acid (49)                           | C. decandra     | leaves          | 33         |
| 3β-O-cis-coumaroylbetulinic acid (50)                      | C. tagal        | aerial parts    | 44         |
| 3β-O-trans-feruloylbetulin (51)                            | C. tagal        | aerial parts    | 44         |
| 3β-O-cis-feruloylbetulin (52)                              | C. tagal        | aerial parts    | 44         |
| 3β-O-trans-coumaroylbetulinic acid (53)                    | C. tagal        | aerial parts    | 44         |
| 3β-O-trans-coumaroylbetulin (54)                           | C. tagal        | aerial parts    | 44         |
| 3β-Z-coumaroyllupeol (55)                                  | C. decandra     | leaves          | 33         |
| 3β-Z-feruloyllupeol (56)                                   | C. decandra     | hypocotyls and fruits | 43    |
| betulin (57)                                               | C. decandra     | leaves          | 33         |
| betulinaldehyde (58)                                      | C. decandra     | leaves          | 33         |
| betulinic acid (59)                                       | C. decandra     | hypocotyls and fruits | 43     |
| betulonic acid (60)                                       | C. tagal        | aerial parts    | 44         |
| lup-20(29)-en-3β,28-diol (61)                              | C. tagal        | roots           | 39         |
| lup-20(29)-en-3β,30-diol (62)                              | C. tagal        | roots           | 36         |
| lup-20(29)-en-3β-hydroxy-28-oic (63)                       | C. tagal        | leaves          | 33         |
| lupenone (64)                                              | C. decandra     | leaves          | 33         |
| lupeol (65)                                                | C. tagal        | hypocotyls and fruits | 43     |
|                                                           | C. tagal        | aerial parts    | 44         |
|                                                           | C. tagal        | roots           | 39         |
| Pimaranes (Diterpenoids)                                   |                 |                 |            |
| 8,15-repoxypimaran-16-ol (125)                             | C. decandra     | roots           | 31         |
| ceriopins C (126)                                         | C. decandra     | roots           | 30         |
| ceriopins D (127)                                         | C. decandra     | roots           | 30         |
| ent-8(14)-pimarene-15R,16-diol (128)                       | C. tagal        | roots           | 45         |
| isopimarin-8(14)-en-15,16-diol (131)                       | C. tagal        | stems and twigs | 38         |
| isopimarin-8(14)-en-16-hydroxy-15-one (132)                | C. tagal        | roots           | 39         |
| methoxy-ent-8(14)-pimarene1-15-one (133)                   | C. tagal        | roots           | 45         |
| Abietane (Triterpenoids)                                   |                 |                 |            |
| abiert-8,11,13-riien-18-oic acid (246)                     | C. tagal        | stems and twigs | 38         |
| Steroids                                                  |                 |                 |            |
| stigmasterol (99)                                         | C. tagal        | roots           | 45         |
| β-sitosterol (96)                                         | C. tagal        | roots           | 45         |
Table 4. Chemical constituents of the bark of *Kandelia candel*

| Compound Class                  | Compound Name                                      |
|--------------------------------|----------------------------------------------------|
| Propargonidin dimers           | afzelechin-(4α→8)- afzelechin (180)               |
|                                | afzelechin-(4α→8)- catechin (181)                 |
|                                | afzelechin-(4α→8)- epicatechin (182)              |
| Procyanidin trimers            | epicatechin-(4β→6)-epicatechin-(4β→6)-epicatechin (188) |
|                                | epicatechin-(4β→6)-epicatechin-(4β→8)-catechin (189) |
|                                | epicatechin-(4β→6)-epicatechin-(4β→8)-epicatechin (190) |
| Proanthocynadins               | cinchonain Ia (184)                               |
|                                | cinchonain Ib (185)                               |
|                                | cinchonain Ila (186)                              |
|                                | cinchonain Ilb (187)                              |
|                                | kandels A-1, A-2, B-1, B-2, B-3, B-4 (193–198)    |
|                                | proanthicyanidin B-1, B-2, C-1 (201–203)          |
|                                | proanthicyanidin trimer (204)                     |
| Flavan-3-ols                   | (–)-epicatechin (172)                              |
|                                | (+)-afzelechin (173)                              |
|                                | (+)-catechin (174)                                |
|                                | (+)-gallocatechin (176)                           |

Table 5. Chemical constituents of the genus *Rhizophora*

| Compound Class and Name | Plant | Plant Part | References |
|-------------------------|-------|------------|------------|
| D-Friedooleananes       |       |            |            |
| 3β-O-E-coumaroyltaraxerol (15) | R. stylosa | stems and twigs | 48 |
| 3β-E-cafeoyltaraxerol (16) | R. mucronata | fruits | 49 |
| 3β-O-Z-coumaroyltaraxerol (19) | R. stylosa | stems and twigs | 48 |
| 3β-taraxerol acetate (20) | R. stylosa | stems and twigs | 48 |
| 3β-taraxerol formate (21) | R. stylosa | stems and twigs | 48 |
| 3β-Z-cafeoyltaraxerol (22) | R. mucronata | fruits | 49 |
| 3β-Z-p-coumaroyltaraxerol (24) | R. mucronata | fruits | 49 |
| 3β-E-p-coumaroyltaraxerol (18) | R. mucronata | fruits | 49 |
| careaborin-(3β-E-p-coumaroyltaraxerol) (18) | R. apiculata | leaves | 47 |
| taraxerol (28)           | R. stylosa | leaves | 50 |
|                           | R. stylosa | leaves | 50 |
|                           | R. mangle | leaves and stems | 51 |
|                           | R. stylosa | leaves | 50 |
|                           | R. stylosa | stems and twigs | 48 |
|                           | R. mucronata | fruits | 49 |
| taraxerone (26)          | R. stylosa | leaves | 50 |
| taraxeryl-cis-p-hydroxycinnamate (24) | R. apiculata | leaves | 47 |
| Lupanes (Triterpenoids)  |       |            |            |
| trans-hydroxycinnamomylupeol (66) | R. mangle | leaves and stems | 51 |
| lupeol (65)              | R. apiculata | stem | 52 |
|                           | R. mucronata | leaves | 17 |
|                           | R. mucronata | stem bark | 53 |
| Oleananes (Triterpenoids) |       |            |            |
| 15α-hydroxy-β-amyрин (67) | R. stylosa | stems and twigs | 48 |
| 3β-O-(4-methoxy)-cinnamoyl-15α-hydroxy-β-amyрин (68) | R. mucronata | stem bark | 53 |
| 3β-O-(E)-coumaroyl-15α-hydroxy-β-amyрин (69) | R. stylosa | stems and twigs | 48 |
| oleanolic acid (70)      | R. mucronata | leaves | 17 |
| β-amyрин (71)            | R. mucronata | root bark | 54 |
|                           | R. mucronata | leaves | 17 |
| Ursanes (Triterpenoids)  |       |            |            |
| Compound                        | Source                             | Type                        | Other Information |
|--------------------------------|------------------------------------|-----------------------------|-------------------|
| Ursolic acid (73)              | *R. mucronata* leaves              | Aliphatic alcohols          | 17                |
| α-amyrin (74)                  | *R. mucronata* root bark           | Aliphatic alcohols          | 54                |
| Aliphatic alcohols             |                                    |                             |                   |
| Dotriacontanol (247)           | *R. apiculata* heartwood           |                             | 55                |
| Hentriacontanol (248)          | *R. apiculata* heartwood           |                             | 55                |
| Nonacosanol (249)              | *R. apiculata* heartwood           |                             | 55                |
| Octacosanol (250)              | *R. apiculata* heartwood           |                             | 55                |
| Triacanthanol (251)            | *R. apiculata* heartwood           |                             | 55                |
| Aliphatic saturated carboxylic acids |                                 |                             |                   |
| Doicosanoic (252)              | *R. apiculata* heartwood           |                             | 55                |
| Henicosanoic (253)             | *R. apiculata* heartwood           |                             | 55                |
| Hentriacontanol (254)          | *R. apiculata* heartwood           |                             | 55                |
| Heptacosanoic (255)            | *R. apiculata* heartwood           |                             | 55                |
| Hexatriacontanol (256)         | *R. apiculata* heartwood           |                             | 55                |
| Octacosanoic (257)             | *R. apiculata* heartwood           |                             | 55                |
| Pentacosanoic (258)            | *R. apiculata* heartwood           |                             | 55                |
| Tetracosanoic (259)            | *R. apiculata* heartwood           |                             | 55                |
| Tetratriacontanoic (260)       | *R. apiculata* heartwood           |                             | 55                |
| Triacanthanoic (261)           | *R. apiculata* heartwood           |                             | 55                |
| Triteracontanoic (262)         | *R. apiculata* heartwood           |                             | 55                |
| Steroids                       |                                    |                             |                   |
| Campesterol (92)               | *R. apiculata* heartwood           |                             | 55                |
| Daucosterol (94)               | *R. mucronata* root bark           |                             | 54                |
| Ergosta-7,22-dien-3β-ol (95)   | *R. apiculata* stem                |                             | 52                |
| Sitosterol (96)                | *R. apiculata* heartwood           |                             | 55                |
| Sitosteryl-3-glucoside (97)    | *R. apiculata* heartwood           |                             | 55                |
| Stigmasterol (99)              | *R. apiculata* heartwood           |                             | 55                |
| Aromatic compound              |                                    |                             |                   |
| Syringaldehyde (160)           | *R. apiculata* heartwood           |                             | 55                |
| Benzoxquinone                  |                                    |                             |                   |
| 2,6-Dimethoxy-p-benzoquinone (162) | *R. apiculata* heartwood     |                             | 55                |
| Labdanes (Diterpenoids)        |                                    |                             |                   |
| Apiculol (263)                 | *R. apiculata* roots               |                             | 56                |
| Rhizophorin A (264)            | *R. mucronata* roots               |                             | 57                |
| Rhizophorin B (141)            | *R. mucronata* roots               |                             | 58                |
| Rhizophorin C (142)            | *R. mucronata* roots               |                             | 58                |
| Rhizophorin D (143)            | *R. mucronata* roots               |                             | 58                |
| Pimaranes (Diterpenoids)       |                                    |                             |                   |
| 15(S)-isopimar-7-en-1-oxo-15,16-diol (124) | *R. apiculata* stem |                             | 52                |
| Rhizophorin E (134)            | *R. mucronata* roots               |                             | 58                |
| Kauranes (Diterpenoids)        |                                    |                             |                   |
| 13,16,17-trihydroxy-ent-9(11)-kauren-19-oic acid (102) | *R. apiculata* stem |                             | 52                |
| 16β,17-13-epoxy-16-hydroxy-ent-kaur-9(11)-en-19-al (101) | *R. apiculata* stem |                             | 52                |
| Methyl-ent-16β,17-dihydroxy-9(11)-kauren-19-oate (118) | *R. apiculata* stem |                             | 52                |
| Methyl-ent-kaur-9(11)-ent-13,17-exopy-16-hydroxy-19-oate (119) | *R. apiculata* stem |                             | 52                |
| Sesquiterpenes                 |                                    |                             |                   |
| Chemical Class          | Plant          | Compounds                                      | Number |
|-------------------------|----------------|-----------------------------------------------|--------|
| Carbohydrate            | R. mucronata   | 1-d-O-methyl-muco-inositol                     | 49     |
|                         |                | adian-5-en-3-ol                               | 53     |
| Phenolic compounds      | R. mucronata   | atranorin                                     | 54     |
|                         | R. stylosa     | protocatechuic acid                           | 50     |
|                         | R. stylosa     | isovanillic acid                              | 50     |
| Xanthone(aromatic ketone)| R. mucronata  | lichixanthone                                 | 54     |
| Aliphatic ketone        | R. mucronata   | palmitone                                     | 54     |
| Flavonoids              | R. stylosa     | rutin                                         | 50     |
|                         | R. stylosa     | astilbin                                      | 50     |
|                         | R. stylosa     | (-)-(3',7-O-diacetyl-epicatechin               | 59     |
|                         | R. stylosa     | (-)-epicatechin                               | 59     |
|                         | R. stylosa     | (-)-3-O-acetyl-epicatechin                    | 59     |
|                         | R. stylosa     | (-)-3',4',5,7-O-pентаacetyl-epicatechin       | 59     |
|                         | R. stylosa     | (+)-afzelechin                                | 59     |
|                         | R. stylosa     | (+)-catechin                                  | 59     |
|                         | R. stylosa     | proanthocyanidin B2                           | 59     |
|                         | R. stylosa     | glabraoside A                                 | 60     |
|                         | R. stylosa     | glabraoside B                                 | 60     |
|                         | R. stylosa     | cinchonain Ia                                 | 60     |
|                         | R. stylosa     | cinchonain Ib                                 | 60     |
|                         | R. stylosa     | (+)-catechin-3-O-a-L-rhamnoside               | 60     |
|                         | R. stylosa     | cinchonain la                                 | 60     |
|                         | R. stylosa     | cinchonain lb                                 | 60     |

### 2.3 Kandelia: There are two species in the mangrove genus Kandelia: K. candel and K. obovata. Only one report is available regarding the chemical constituents of plants of this genus. A few tannin compounds have been reported from K. candel. Investigation of K. obovata for its chemical constituents remains to be observed. 24 phenolic compounds including three propelargonidin dimmers, three procyandin trimers, fourteen proanthocyanidins and four flavan-3-ols have been isolated from the bark of K. candel Druce.³⁶

### 2.4 Rhizophora: The mangrove genus Rhizophora has ten species: R. apiculata, R. harrisonii, R. lamarkii, R. mangle, R. mucronata, R. racemosa, R. samoensis, R. selata, R. stylosa and R. annamalayana. Of these ten species, chemical constituents have only been reported in R. apiculata, R. mangle, R. mucronata, and R. stylosa. These reports reveal a total of 34 metabolites from R. apiculata, two metabolites from R. mangle, 23 metabolites from R. mucronata and 25 metabolites from R. stylosa, thus a total of 81 different metabolites from the genera Rhizophora, with details shown in Table 5.

The chemical investigation carried out by Majumdar and Patra in 1976 resulted in the isolation of β-amyrin, β-amyrone, taraxerol, β-sitosterol, and triacantanol from R. apiculata.²⁷ Later in early nineties Kokpol and his team had identified three terpenoids, five long chain aliphatic alcohols, eleven long chain aliphatic saturated carboxylic acids, three steroids, 2,6-dimethoxy-p-benzoquinone, syringaldehyde and sitosterol 3-glucoside from this plant species. Also, five kaurenanes, one labdane and one pimarane diterpenoids and one lupane triterpenoid are reported so far from R. apiculata.

The study conducted by Williams et. al³¹ reported the isolation and chemical characterisation of taraxerol and cinnamomylupeol, two triterpenoids from the leaves and stems of Rhizophora mangle L. A variety of steroids, diterpenoids and triterpenoids were reported from the leaves and bark of R. mucronata. A few beyeranes (diterpenoids) were identified from this plant, and are unique to this species. Only triterpenoids of the classes oleananes and D-friedooleananes from R. stylosa are reported to date.
3 Bioactivities

3.1 Bioactivities of Compounds Identified: With stably transfected HepG2 cells, three new dammarane triterpenes; bruguierins A–C and a new cyclic 4-hydroxy-dithiolane-1-oxides; brugierol and isobrugierol, were isolated from the flowers of *Bruguiera gymnorrhiza*. These phytochemicals activated an antioxidant response element (ARE luciferase activation) with EC\(_{50}\) values of 7.8, 9.4, 15.7, 56.7, 3.7 and 1.8 \(\mu\)M, respectively. Furthermore, bruguierin A, brugierol and isobrugierol also inhibited phorbol ester-induced NFκB activation) with EC\(_{50}\) values of 7.8, 9.4, 15.7, 56.7, 3.7 and 1.8 \(\mu\)M, respectively, while bruguierin A and brugierol selectively inhibited cyclooxygenase-2 (COX-2) enzyme involved in the regulation of insulin signaling and which is regarded as a key for treatment of type III diabetes and obesity\(^{27}\). One of the aromatic compounds extracted from the stem of *B. gymnorrhiza*, brugierol C showed moderate activity against gram-positive and gram-negative bacteria including mycobacteria and resistant strains (MICs 12.5 \(\mu\)g/mL)\(^{28}\).

The compounds 16α-17,19-ent-kaurenadiol; 13-hydroxy-16-ent-kaurene-19-ol and 16-ent-kaurene-19-ol showed promising activity against K-562 (human chronic myeloid leukemia) and L-929 (mouse fibroblasts) of which 16-ent-kaurene-19-ol showed the great selectivity for K-562 (IC\(_{50}\) value of 0.37 and 6.1 \(\mu\)M respectively\(^{16,26}\).

The compounds 16α-17,19-ent-kaurenadiol; 13-hydroxy-16-ent-kaurene-19-ol and 16-ent-kaurene-19-ol showed promising activity against K-562 (human chronic myeloid leukemia) and L-929 (mouse fibroblasts) of which 16-ent-kaurene-19-ol showed the great selectivity for K-562 (IC\(_{50}\) 6.8 \(\mu\)g/mL)\(^{25}\).

The 15 membered macrocyclic polysulfide, gymnorrhizol, possesses an novel carbon skeleton which was isolated from *B. gymnorrhiza* and exhibited potent inhibitory activity against protein tyrosine phosphatase 1B (PTP1B). PTP1B is an enzyme involved in the regulation of insulin signaling and which is regarded as a key for treatment of type III diabetes and obesity\(^{27}\). One of the aromatic compounds extracted from the stem of *B. gymnorrhiza*, brugierol C showed moderate activity against gram-positive and gram-negative bacteria including mycobacteria and resistant strains (MICs 12.5 \(\mu\)g/mL)\(^{28}\).

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Brontispa longissima at a concentration of 1 mg/mL. Dolabr-4(17),15(16)-dien-3-one, isopimar-8(14)-en-15,16-diol, isopimar-8(14)-en-16-hydroxy-15-one, lupeol, lup-20(29)-en-3β,28-diol and lup-20(29)-en-3β-hydroxy-28-oic acid were isolated from the roots of marine mangrove C. tagal which were evaluated for the activation of caspase-3 enzyme using caspase-3 colourimetric assay. Caspase-3 enzyme was activated by all compounds in cleaving pNA from Ac-DEVD-pNA in the presence of caspase-3-inhibitor; Ac-DEVD-CHO.

2,6-dimethoxy-p-benzoquinone isolated from R. apiculata was identified as an active constituent component against fungi, bacteria and boll weevils. Taraxerol and cinnamoyllupeol, are two triterpenoids derived from the leaves and stems of Rhizophora mangle L., were found exhibit insecticidal activity towards Cylas formicarius: one of the most destructive pests of the sweet potato.

Among the compounds isolated from the leaves of Rhizophora stylosa, taraxerol has been confirmed to have growth inhibitory effects of Hela and BGC-823 with IC$_{50}$ of 73.4 µmol/L and 73.3 µmol/L, respectively, while cis-careaborin may inhibit the growth of BGC-823 and MCF-7 with IC$_{50}$ of 45.9 µmol/L and 116.0 µmol/L, respectively. Furthermore, the presence of astilbin and rutin were initially reported to stimulate the proliferation of mice splenic lymphocytes markedly in a dose-dependent manner. The
compounds, (−)-epicatechin, (−)-catechin, 3-O-acetyl-(−)-epicatechin, 3,7-O-acetyl-(−)-epicatechin, (+)-afzelechin, cinchonain 1b and proanthocyanidin B2 were isolated from the same plant displayed DPPH radical scavenging activity which were comparable to that of the positive control butylated hydroxytoluene (BHT). Proanthocyanidin B2 showed the strongest activity with IC\(_{50}\) 4.3 µg/mL, being four fold greater than the positive control, BHT (IC\(_{50}\) 18.0 µg/mL). The antioxidant flavan-3-ol glycosides from \textit{R. stylosa} showed an increase in their radical scavenging activities with increase in number of catechol moieties present in the molecules\(^6\).

3.2 Bioactivities of Mangrove Extracts: Various publications have reported the biological activities of mangrove extracts. The components of crude alkaloid mixtures from \textit{B. sexangula} and \textit{B. exarista} were identified as tumor inhibitors\(^6\). A polysaccharide extracted from the leaves of \textit{B. cylindrica}, \textit{R. apiculata} and \textit{R. mucronata} of \textit{Rhizophoraceae} along with some other mangrove plants exhibited positive activity against human immunodeficiency viruses (HIV)\(^6\). All parts of \textit{Ceriops decandra} have proven antiviral activity\(^6\). It also possess promising antibacterial\(^6\), antiinflammatory\(^6\), and antidiabetic activity\(^6\). The leaves and bark extract of \textit{C. tagal} shows antibacterial activity\(^6\). Phenolics are important components of the leaf extract and hypocotyls of \textit{K. candel} and show excellent antioxidant activities\(^6\). Therefore, \textit{K. candel} can be a good candidate for further development as an antioxidant medicine. During the study on the antibacterial activities of mangrove extracts against two antibiotic resistant

\textbf{Figure 3-2.} Lupanes from \textit{Rhizophoraceae} mangroves
Figure 4. Oleananes, ursanes and dammaranes from Rhizophoraceae mangroves
pathogenic bacteria *Staphylococcus aureus* and *Proteus* sp., it was observed that the ethyl acetate extract of *B. Sexangula* and *R. apiculata* also possessed promising antibacterial activity. This antibacterial activity was also reported in a study showing that gallic acid was extracted from hydrolysable tannin from the barks of *R. apiculata*. The gallic acid possessed a significant antyeast (anticandidal) activity towards some yeast species of medical importance. It is anticipated that gallic acid from *R. apiculata* is a novel antyeast agent which may be useful in the treatment of candidiasis. Alcoholic extract of the leaves of *Rhizophora apiculata* from the mangrove forest of Sunderbans, West Bengal, India were prepared and displayed manglycemic/anti-hyperglycemic activity in streptozotocin induced diabetic rats fed a glucose bolus. The results of this study revealed that this plant extract had potential hypoglycemic action. The cholinesterase inhibition activity of *R. lamarckii* was established by Natarajan et al. 2009. The antihyperglycaemic effect of *R. mangle* was studied. The leaf extracts of three mangrove plants of Rhizophoraceae family; *Rhizophora mucronata*, *R. apiculata* and *R. annamalayana* were found to have potential anti-diabetic capacity due to the presence of an insulin-like protein. The various studies mentioned, provide scientific support for the use of the mangroves in folklore medicine for the treatment of diabetes. Various mangrove plants were tested for their antioxidant capacity. It was found that the Rhizophoraceae mangroves showed comparatively higher antioxidant capacity which can be attributed to their higher phenolic content. Additionally, the mangrove plants of Rhizophoraceae family are the source of potent antiviral substances.

### 4 Chemotaxonomy

The chemical constituents of mangrove plants of the three true mangrove genera (Rhizophoraceae); *Bruguiera*, *Ceriops* and *Rhizophora*, are the diterpenoid class kauranes exist in the genera *Bruguiera* and *Ceriops*, however kauranes are absent in the genus *Rhizophora*. The genus *Bruguiera* is characterised by the presence of disulphides and polydisulphides which are unique to the genus. Thus they can be considered as significant chemotaxonomic markers of this genus. Also, it was observed that ent-pimarane coexists with isopimarane in the genus *Bruguiera*. Interestingly, dolabranes only exist in the genus *Ceriops* making it a significant chemotaxonomic marker. Similarly, labdane was found only in the genus *Rhizophora*, making it a significant chemotaxonomic marker of that specific genus.

Furthermore, extensive investigation is needed to identify and classify the chemical constituents of mangrove plants to construct a thorough basis for the chemotaxonamic studies of these versatile plants.

### 5 Conclusions

In this review, the chemistry and bioactivities of mangroves plants of Rhizophoraceae family have been summarised. Two types of diterpenoids; beyerane and pimarane, and three types of triterpenoids; lupane, oleanane and dammarane, are common chemical constituents ubiquitously found in this family, including 268 metabolites. To date, the chemical constituents from all the mangrove plants of this family have not been investigated. It is clear that mangrove plants can provide a new
Figure 6. Steroids from Rhizophoraceae mangroves
Figure 7. Kauranes, pimaranes and beyeranes (diterpenoids) from Rhizophoraceae mangroves
Figure 8. Sulphur compounds from Rhizophoraceae mangroves

Figure 9. Sulphur compounds from Rhizophoraceae mangroves

Figure 10. Carbohydrate and benzoquinone identified from Rhizophoraceae mangroves

Phenolic compounds
Figure 11. Phenolic compounds from Rhizophoraceae mangroves

**Flavonoids**

![Chemical structures of flavonoids](image)
Figure 12. Flavonoids from Rhizophoraceae mangroves

**Lignans**

214 H-7°/H-8° = H-7°/H-8° = H-7°/H-8° = erythro
215 H-7°/H-8° = threo, H-7°/H-8° = H-7°/H-8° = erythro
Figure 13. Lignans from Rhizophoraceae mangroves

Dolabranes

216

217 R₁ = OH, R₂ = H, R₃ = COOH
225 R₁ = OH, R₂ = H, R₃ = CH₂=CH
231 R₁ = H, R₂ = H, R₃ = CH₂=CH
233 R₁ = H, R₂ = H, R₃ = OH

218 X = O, R₁ = OH, R₂ = HO–CH₂(O)
219 X = O, R₁ = OH, R₂ = COOH
220 X = H₂, R₁ =H, R₂ = HO–CH₂(OH)
229 X = O, R₁ = OH, R₂ = H₂C=CH
232 X = O, R₁ = OH, R₂ = OH

221
222
223

210 7°,8° = 7°,8° = erythro
211 7°,8° = erythro, 7°,8° = threo
212 7°,8° = 7°,8° = threo
Figure 14. Dolabranes and dimeric diterpenoids from Rhizophoraceae mangroves

Aliphatic alcohols

\[ \text{HO} \quad 247 \quad \text{OH} \quad 248 \quad \text{OH} \quad 249 \quad \text{OH} \quad 250 \quad \text{OH} \quad 251 \]

Aliphatic acids

\[ \text{COOH} \quad 252 \quad \text{COOH} \quad 253 \quad \text{COOH} \quad 254 \quad \text{COOH} \quad 255 \quad \text{COOH} \quad 256 \quad \text{COOH} \quad 257 \quad \text{COOH} \quad 258 \quad \text{COOH} \quad 259 \]

\[ \text{COOH} \quad 260 \quad \text{COOH} \quad 261 \quad \text{COOH} \quad 262 \]

Figure 15. Aliphatic alcohols and acids in Rhizophoraceae mangroves
bank of phytochemical substances that are biologically active substances, with novel structures. It is essential to systematically conserve the biodiversity in the mangrove ecosystem and for the proper of this ecosystem for the future use of humanity.

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