DOI: 10.55522/jmpas.V13I5.6633 ISSN NO. 2320 – 7418

International peer reviewed open access journal

Journal of Medical Pharmaceutical and Allied Sciences

Journal homepage: www.jmpas.com CODEN: JMPACO

Review article

Botanical, phytochemical and pharmacological profile of the mangrove plant *Kandelia candel* (L.) Druce

Sonal M. Manohar *

Department of Biological Sciences, Sunandan Divatia School of Science, SVKM's NMIMS (Deemed-to-be) University, Mumbai, Maharashtra, India

Corresponding author: Sonal M. Manohar, ✉ manohar.sonal@gmail.com , **Orcid Id**: https://orcid.org/0000-0001-6245-9640

Department of Biological Sciences, Sunandan Divatia School of Science, SVKM's NMIMS (Deemed-to-be) University, Mumbai, Maharashtra, India

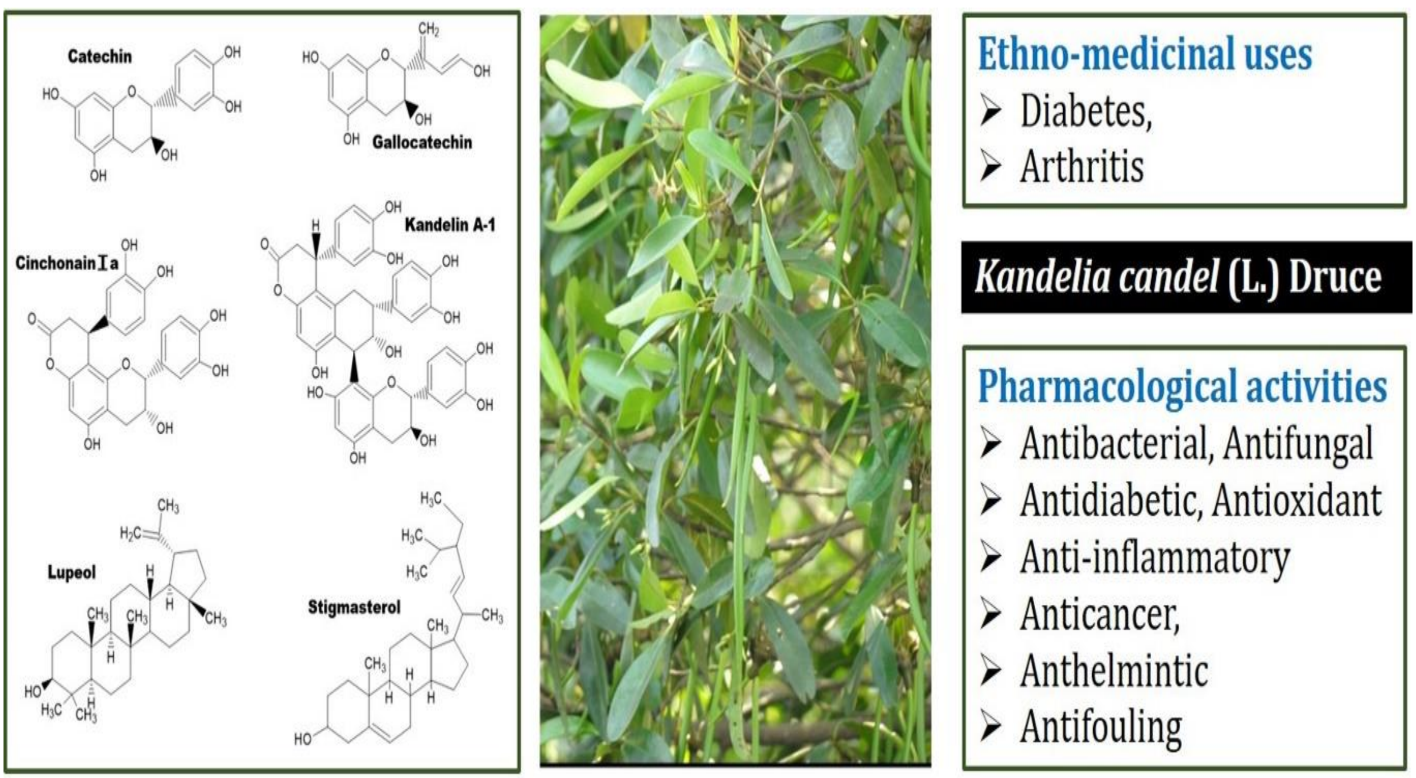
Received - 21-07-2024**, Revised** - 27-08-2024, **Accepted** - 15-09-2024 **(DD-MM-YYYY)**

Refer This Article

Sonal M. Manohar, 2024. Botanical, phytochemical and pharmacological profile of the mangrove plant *Kandelia candel* (L.) Druce. Journal of Medical Pharmaceutical and Allied Sciences, V 13 - I 5, Pages - 6763 – 6772. Doi: https://doi.org/10.55522/jmpas.V13I5.6633.

ABSTRACT

Kandelia candel L. Druce (family Rhizophoraceae) is a true / major mangrove that has a wide-spread distribution along the coastal areas of the Indo-west Pacific region of the earth. It is commonly found along the coasts of India and a few South East Asian countries. Its parts have numerous applications in leather, textile, furniture industries, and is also used by the traditional health practitioners / healers to treat diabetes. It is known to be producing a variety of phytochemicals. Extracts and compounds isolated from *K. candel* have exhibited noteworthy biological activities. An attempt has been made to compile the up-to-date information on this mangrove plant from globally recognised scientific databases. This review would provide necessary informationtoformulate the possible application of this common mangrove in standard as well as complementary medicine.



Keywords: Antidiabetic, Antimicrobial, Bioactivity, Phytochemicals, Phytomedicine, Mangroves.

INTRODUCTION

The use of plants and plant derived products for treating various diseases and disorders is an age old practice. Phytochemicals have served as lead molecules in numerous drug discovery programmes. Mangroves are unique and important members of kingdom plantae that have the ability to survive in the coastal and estuarine habitats having higher salinities. They are well-known for their secondary metabolites and reported to have a myriad array of bioactivities. [1-3].

The Rhizophoraceae family comprises of 17 genera having 120 plant species widely distributed in the tropical and sub-tropical countries of the globe [4, 5]. Out of these 17 genera, only 4 genera viz. *Rhizophora*, *Ceriops*, *Bruguiera*, and *Kandelia* represent the true or exclusive type of mangroves. The genus *Kandelia* has been represented by two species viz. *K. candel* and *K. obovata*. The former has a wider global distribution and therefore has been studied relatively more [6].

Taxonomic Description

Van Rheede in the year 1686, first discovered this species in the Malabar region of Kerala, India and was given a name as "Tsjerou-kandel" perhaps based on its local name *kantal* in Malabar. Based on the resemblance of its hypocotyle with a candle, Linnaeus later changed its name to *Rhizophora candel*. Finally, the species got the recognition as monotypic species from the *Kandelia* genus and now is universally accepted as *Kandelia candel*. Homotypic synonym is *Rhizophora candel* L. whereas heterotypic synonym is *Kandelia rheedei* Wight & Arn [7].

The species is known in English language by the common names of Narrow-leaved Kandelia, and Dichotomous Cymed Mangrove. Owing to its widespread occurrence, there are various vernacular names associated with this mangrove as seen along with its taxonomic classification in the Table 1.

Table 1: Taxonomic classification, local and vernacular names of *K. candel* [6-14]

Taxonomical classification	Country and states-specific local and vernacular names	
Kingdom: Plantae Subkingdom: Viridiplantae Infrakingdom: Streptophyta Phylum (division): Tracheophyta Subphylum (subdivision): Spermatophytina Class: Magnoliopsida Superorder: Rosanae Order: Malpighiales Family: Rhizophoraceae Genus: *Kandelia* Species: *K. candel*	Brunei:*Lingajong, Lingajong laut, Pulut-pulut*	India,Andhra Pradesh state (Telugu): *Kandigala, Thuvarkandan*
	China: *qui qie*	Goa state (Konkani):*Chipin*
	Japan:*Mehirugi*	Kerala (Malayalam): *Kantal, Cheru-kantal, Eluttanikkantal*
	Thailand:*Rang ka thae*	Maharashtra state (Marathi):*Kandal*
	Indonesia:*Beus, Pulut-pulut, Pisang-pisang laut*	Odisha state (Odia): *Sinduka, Rasunia*
	Malaysia:*Lingayong, Beus, Mempisang, Bakau Aleh-aleh, Pulut-pulut, Berus-berus*	Karnataka state (Kannada): *Kaandale*
	Philippines:*Bakauan baler*	Tamil Nadu state (Tamil): *Kantal, Puk-kantal, Tuvar-k-kantal*
	Vietnam: *vẹt [dd]ìa, Trang vẹt thang*	West Bengal state (Bengali): *Garia, Guria*
	Singapore:*Berus-berus, Pisang pisang, Beras beras, Pulut pulut*	English: *Narrow-leaved Kandelia*

Distribution and Habitat

K. candel is a core mangrove species of the Indo-West Pacific region of the world [15]. The species has its origin in India and is found along both the west and east coasts as well as on the Andaman and Nicobar islands. However, it is found comparatively rarely in the Indian states like Tamil Nadu and Andhra Pradesh situated on the east coast. From India, it is found growing eastwards through the South China Sea to Southeast Asia, Guangdong province (southern China), Hong Kong, Taiwan and southern parts of Japan. In Southeast Asia, it has patchy and local distribution and has been documented from countries starting from Myanmar extending up to western parts of Indonesia (including the coastal areas of northern Sumatra and West Borneo) [6].

Being a large shrub or small to moderate sized tree, *K. candel* and other members of Rhizophoraceae have been observed forming mangrove forests. It is often seen growing along muddy river banks or estuaries under the shade of other mangroves such as *Avicennia officinalis* and *Rhizophora* spp. In the middle zone of the mangrove ecosystem. It has been observed thriving in the mesohaline zone having 5-18% salinity and silty clay [7].

Botany

K. candel (Figure 1) usually grows as a large shrub or a small tree reaching a maximum height of 7 m. However, in the Philippines, specimens of 9 m have been recorded [16]. *K. candel* has a thickened base of the stem. Bark colour is greyish-red or brown, has a smooth texture and shows the presence of lenticels. Leaves are simple, elliptic-oblong shaped and measure 6-11 cm long to 2.5-4.5 cm broad. Lateral veins are mostly seen in pairs of 8-11. Flowers are white in colour, 1.5-2 cm in length and usually appear in clusters of 4 (sometimes 9) in axillary cymes. Sepals are light green in colour during blooming whereas 1.4 cm long petals are deeply bifid; each half showing 3-5 bristles. The leaf stalk has in general, a length 1.5 cm. Stamens are always distinctly longer than the style. Bracteole has a V-shape. Anthers appear curved and are grooved. The hypocotyl is cylindrical, 20-40 cm long. It is usually mistaken as 'fruit', and appears club-shaped with attenuate apex. The fruit is green in colour, is ovoid, and 1.5-2.5 cm long. Fruits show reflexed calyx lobes. Germination is viviparous. The flowering and fruiting in *K. candel* have been observed to differ from region to region. In general, flowering occurs almost throughout the year whereas fruiting is observed from July to November post falling of hypocotyl [6, 17-19]. It has chromosome number 2n = 38 [20].

K. obovata differs morphologically from *K. candel* by having a smaller height of the plant (up to 3 m), obovate shape of the leaf, white colour of the sepal while blooming, a longer or subequal style compared to stamens, an U-shaped bracteole, a cone shaped anther without any distinct grooves and a much shorter hypocotyl (15-20 cm long) with acuminate apex [21].

Figure 1: Photographs of *K. candel* in its natural habitat showing different parts

Local uses

The most common use of the wood of *K. candel* is as fuel (firewood) or for making charcoal. It is also employed in making temporary constructions. Generally a 14-17% tannin content has been reported from its bark. Tannin extracted from the bark finds its usage in leather industries, for increasing the durability of fish nets and also for dyeing clothes in red and brown shades. It is also used as a green manure to increase the quality of soil and as a fodder [13, 17, 18].

In northern Vietnam, beekeepers have been increasing the honey production triple times higher in summers by temporarily placing their bee hive boxes near the mangrove forests. The honey bees forage on the flowers of *K. candel*, blooming between July to September thereby producing large amounts of quality honey [22, 23].

Indirect & Ecological Benefits

K. candel like most other mangroves plays many ecological roles. Acting as a wind breaker, it helps in stabilizing soil bunds. It has been observed to provide shelter, shade, and food to a number of fauna ranging from planktons to birds. Roots of this mangrove, act a good soil and mud binder, thus promoting alluvium deposition and preventing erosion of soil [17]. In provinces of southern China (Zhanjiang, Hong Kong), forestry bureau has carried out mass plantations of *K. candel* for restoration of wetlands and to maximise these benefits [6].

Ethnomedicinal uses

K. candel has been traditionally prescribed by the local healers to mainly treat diabetes. In the Sundarban forest area, juice prepared from the stem / bark is consumed for curing diabetes by the locals and therefore plays an important role in folk medicine [11]. Along the West coast of India, especially in the Goa and Maharashtra states, a preparation made with ginger and black pepper is given to diabetic patients [17]. Usefulness in diabetes is also reported from Bhitarkanika wildlife sanctuary, Odisha [13]. The bark is reported to be used, along with dried ginger or long piper and rosewater, for treating diabetes [24]. In Guangdong province of the southern China, roots of *K. candel* are used in chronic arthritis [25].

Phytochemistry

Primary metabolites in *K. candel* include various carbohydrates and sugars, proteins and amino acids, lipids and fatty acids whereas a wide range of secondary metabolites belonging to classes such as phenolics, tannins and terpenoids, alkaloids etc. have been documented.

Phytochemical classes such as carbohydrates, proteins, amino acids, alkaloids, saponins, phenolics, tannins, flavonoids, glycosides and terpenoids have been reported from the bark extracts prepared in chloroform, acetonitrile and water. Cardiac glycosides could not be detected in either fractions [26]. Qualitative analysis of eleven different phytochemical constituents present in the crude leaf extracts of *K. candel* prepared in ethanol, methanol and water was carried out [27]. Except anthraquinone and phlobatanin, presence of remaining nine constituents viz. Alkaloids, flavonoids, glycosides, lignin, phenols, saponins, sterols, tannins, and fats - oils were detected in the extracts. Few constituents were found to be solvent specific and could not be detected in the extract prepared using other solvents in spite of performing different analytical tests.

A comparative biochemical study on five different mangrove species of Rhizophoraceae family found in Kochi, Kerala state, India has been carried out [28]. Different concentrations of macro- and micronutrients as well as macromolecule classes present in the leaves and bark of *K. candel* have been listed in the Table 2.

Out of 5 mangroves studied, *K. candel* did share the highest carbon content stored in its leaves and bark thus acting as a major contributor to the carbon budget of the geographicm al location under study. Carbon fixing and accumulating capacity of mangroves especially *K. candel* was clearly highlighted indicating their role in combating global warming and climate change. Microelements such as manganese, copper and zinc which are well recognized for their crucial role in plant metabolism were found to be in higher concentrations in *K. candel*. Lowest values of Na/K were recorded in the leaves of *K. candel* compared to the other 4 mangroves under investigation indicating the efficient salt exclusion mechanism at work in this mangrove species [28]. *K. candel* was also found to contain comparatively higher concentrations of macromolecules such as carbohydrates, proteins and lipids and was therefore exhibited higher calorific values vindicating its wide use as a firewood or for making charcoal. Higher lipid content in the *K. candel* collected in Japan was also reported by Mfilinge et al, [29].

Soxhlet crude extract prepared in the solvent chloroform was subjected to GC-MS analysis. Comparing the retention time and peak area with the database library, a total 23 compounds were identified present in the extract (Table 3). A perusal of literature indicated that the many of these compounds were biologically important having previously reported antibacterial, antifungal, antioxidant, anticancer, anti-inflammatory, diuretic, antiarthritic and antiasthmatic activities [26].

Table 2: Biochemical compositions of constituents of *K. candel*

Macronutrients	**Leaves**	**Bark**
Carbon %	45.02	46.33
Hydrogen %	6.73	6.41
Nitrogen %	1.73	0.83
Sulphur %	0.48	0.21
Phosphorus (mg/g)	1.39	1.17
Potassium (mg/g)	16.5 ± 0.21	5 ± 0.2
Magnesium (mg/g)	3.41 ± 0.12	2.63 ± 0.07
Micronutrients		
Sodium (mg/g)	18.5 ± 0.86	12 ± 1.12
Iron (mg/kg)	211.3 ± 0.57	58.4 ± 0.55
Copper (mg/kg)	4.7 ± 0.07	4.9 ± 0.16
Zinc (mg/kg)	14.85 ± 1.41	17.6 ± 0.21
Manganese (mg/kg)	235 ± 1.41	110 ± 1.51
Cobalt (mg/kg)	5.22 ± 0.02	4.67 ± 0.02
Nickel (mg/kg)	4.82 ± 0.16	2 ± 0.06
Lead (mg/kg)	4.5 ± 0.1	1 ± 0.03
Cadmium (mg/kg)	0.55 ± 0.01	Not detected
Organic macromolecules		
Carbohydrates (mg/g)	160.74 ± 1.08	194.05 ± 0.95
Low molecular weight carbohydrates LMWC (mg/g)	80.07 ± 1.44	177.82 ± 2.55
Polysaccharides (mg/g)	78.88 ± 2.52	17.36 ± 0.19
Lipids (mg/g)	56.08 ± 0.62	59.01 ±1.44
Proteins (mg/g)	15.93 ± 0.14	34.27 ± 2.46
PRT/ CHO	0.10	0.18
LPD/CHO	0.35	0.30
Proximate analysis		
Calorific value (K Cal / g)	1.3 ± 0.03	1.5 ± 0.06
Ash %	9.0 ± 0.67	8.5 ± 0.79
Leaf water content %	72.16	-

Table 3: GC-MS analysis of *K. candel* extract

Compound name	**Compound name**	**Compound name**
Phenol, 2,5-bis(1,1-dimethylethyl)-	cis-2-Methyl-7-octadecene	Hexadecen-1-ol, trans-9-
cis-2-Methyl-7-octadecene	4"a-Methyl-8"-methylidene decahydro-2"H-dispiro[bis(cyclopropane)-1,1'2'	Docosahexaenoic acid, 1,2,3-propanetriyl ester
cis-5,8,11,14,17-Eicosapenta-enoic acid	2-Piperidinone, N-[4-bromo-n-butyl]-	3-Trifluoroacetoxypentadecane
Cholest-22-ene-21-ol, 3,5-dehydro-6-methoxy-, pivalate	Digitoxin	1-Hexadecanol, 2-methyl-
1-Octanol, 2-butyl	Dodecane, 1,2-dibromo-	Z,Z,Z-1,4,6,9-Nonadecatetraene
Heptadecane, 9-hexyl	4-Trifluoroacetoxytridecane	1-Heptatriacotanol
Cholesta-8,24-dien-3-ol, 4-methyl-, (3á,4à)-	tert-Hexadecanethiol	9-Octadecen-12-ynoic acid, methyl ester
Cholesta-5,7,9(11)-trien-3-ol acetate	2-[4-methyl-6-(2,6,6-trimethylcyclohex-1-enyl)hexa-1,3,5- trienyl] cyclohex-1- en- 1-carboxaldehyde	

Table 4: Compounds isolated from different parts of *K. candel*

Compounds isolated/ detected	Part used	Ref.
afzelechin-(4α→8)- afzelechin, afzelechin-(4α→8)- catechin, afzelechin-(4α→8)- epicatechin, epicatechin-(4β→6)-epicatechin-(4β→6)-epicatechin, epicatechin-(4β→6)-epicatechin-(4β→8)-catechin, epicatechin-(4β→6)-epicatechin-(4β→8)-epicatechin, cinchonain Ia, Ib, IIa, IIb, kandelins A-1, A-2, B-1, B-2, B-3, B-4, proanthicyanidin B-1, B-2, C-1, proanthicyanidin trimer, (–)-epicatechin, (+)-afzeleczhin, (+)-catechin, (+)-gallocatechin	Bark	[30]
epicatechin, epigallocatechin and derived condensed tannins	Leaves	[31]
oleanolic acid, ursolic aldehyde, cis-3-O-p-Hydroxycinnamoyl ursolic acid, β-sitosterol, betulin (triterpenes); (2S)-3-O-Octadeca-9Z,12Z,15Z-trienoylglyceryl-6'- O-(α-D-galactopyranosyl)-β-D-galactopyranoside, (2S)-3-O-Octadeca-9Z,12Z,15Z-trienoylglyceryl-O-β-D-galactopyranoside (glyceryl glycosides)	Leaves and branches	[32]
kandelside (sesquiterpene glycoside); protocatechuic acid, caffeic acid, chlorogenic acid, threo and erythro-1-C-syringyl-glycerol, engeletin, syringaresinol-β-D glucoside, isorhamnetin 3-O- β -D-glucopyranoside, isorhamnetin 3-O-[a-rhamnopyranosyl-(1-6)-β-glucopyranoside], kaemferol-3-O-rhamnoside, kaempferol 3-neohesperidoside, quercetin-3-O-glucoside, quercetin-3-O-rutinoside, cathechin, epicathechin (phenolics); blumenol C glucoside, (3R,9S)-megastigman-5-ene-3,9-diol 3-O-β -D-glucopyranoside, corchoionoside C (megastigman glycosides)	Leaves and stem	[33]
mehirugins A - C (guaianolides); notoserolide, matricarin (sesquiterpenoids) and a novel Eudesmane-type sesquiterpenoid	Leaves	[34]
lupeol, β(α)-amyrin, 9,19-cyclolanost-25-en-3b-ol, 9,19-Cycloergost-24(28)-en-3-ol,4,14-dimethyl-,(3b, 4a, 5a) (sterol esters)	Leaves and roots	[35]
campesterol, stigmasterol, β-sitosterol, Lanosterol, β-amyrin, α-amyrin, Lupeol, Cycloartenol (isoprenoids)	Leaves and roots	[36]

A wide variety of pure compounds belonging to various phytochemical classes have been isolated from different parts of *K. candel* as summarized in Table 4 [30-36]. Hsu et al, isolated 25 novel polyphenolic compounds from the bark of *K. candel* collected from Taipei. The compounds belonged to proanthocynadins, procyanidin trimers, propelargonidin dimers, and flavan-3-ols which are sub-classes of condensed tannins and flavonoids [30]. The presence of condensed tannins (106.35 mg/g) was also reported from the leaf samples collected from Hainan, China [31]. They were identified as mixtures of epicatechin- derived procyanidins and epigallocatechin-derived prodelphinidins. Condensed tannins having procyanidins as the major component and prodelphinidins as the minor component were detected in the purified fractions of the acetone hypocotyl extract. The purified fraction exhibited strong antioxidant activity [37]. In a recent study, 72 plants were investigated in China for their tannin content and purity. Bark of *K. candel* was found to be a rich source of tannin with more than 20% content and more than 70% purity [38].

Minakawa et al, have reported isolation of six different compounds which belonged to guaianolides, and sesquiterpenoids from methanol leaves extract. Leaf samples were collected from a mangrove forest in Bangladesh [34]. Five triterpenes and two novel glyceryl glycosides isolated and characterized from the leaves and branches collected from Vietnam exhibited promising anti-inflammatory activity [32]. Nineteen compounds belonging to phytochemical classes such as sesquiterpene glycosides, phenolics, and megastigman glycosides have been isolated with few of them having potent anti-inflammatory activity [33].

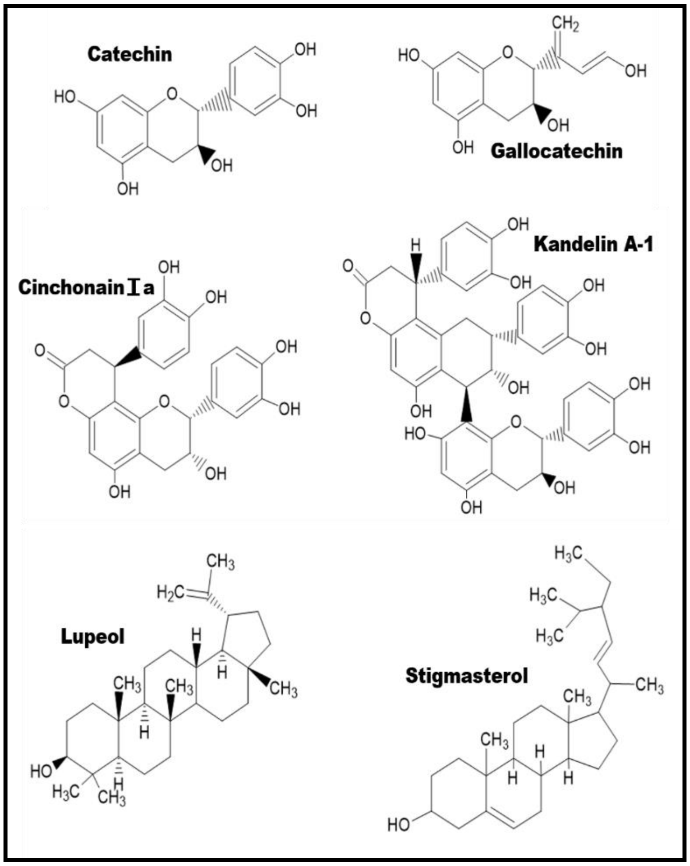
Isoprenoids (comprising phytosterols and triterpenoids) which are known for their important bioactivities along with their roles they confer to the mangrove plants for surviving under the salt stress have been also documented in *K. candel*. Oku et al, reported 11 lipid classes present in the roots and leaves with sterol ester being the most dominant lipid class [35]. Free triterpenoid content was found to increase with increase in salinity highlighting the relevance of lipid proportions to tolerate salt stress. Proportions of triterpenoids and phytosterols have been found to vary in parts of the plant. Eight isoprenoids were detected in the leaves having around 73% triterpenoids and 27% phytosterols whereas stigmasterol and other phytosterols (92%) formed the major proportion of isoprenoids in the roots [36].

Floral scent, which plays a pivotal role in attracting pollinating agents, has been studied in *K. candel* and was found to be a mixture of only two nitrogen-containing compounds viz. Indole and methyl anthranilate. Presence of these compounds clearly indicate that *K. candel* is pollinated by insects such as bees, butterflies, bugs, and beetles [39].

Representative novel compounds isolated from *K. candel* have been shown in the Figure 2

DOI: 10.55522/jmpas.V13I5.6633 **ISSN NO. 2320 – 7418**

Figure 2: Structures of key compounds isolated and characterized from *K. candel*



Pharmacological Activities
Antibacterial

Emergence of multidrug-resistant (MDR) bacterial strains has proven to be a major challenge to the existing antibiotics. Natural products such as phytochemicals could therefore play a crucial role in providing lead molecules in developing new antibiotics [40, 41].

Jasna et al, investigated the antibacterial potential of the extracts prepared from leaves and bark of *K. candel* collected from Kannur district, Kerala state, India [42]. Soxhlet apparatus was used to sequentially prepare the extracts from the dried plant parts using four solvents of different polarity. Different concentrations of crude extracts were then tested against four bacteria. Overall results vindicated the antibacterial activity of the *K. candel* extracts with bark extracts showing comparatively higher zone of inhibition than the leaf extracts. Acetonitrile and chloroform were found to be better solvents to extract antibacterial principles whereas water extracts showed poor results. *Pseudomonas aeruginosa* and *Escherichia coli* (both gram negative) were most vulnerable to the extracts followed by *Staphylococcus aureus* (gram positive) while facultative anaerobic gram positive bacterium *Streptococcus mutans* remained quite resistant [42].

Antifungal

Extracts prepared from the roots, stems as well as leaves of five different mangroves were tested against several fungal pathogens commonly attacking local plants. Extracts prepared from the roots of *K. candel* significantly inhibited the growth of all the four fungal parasites viz. *Alternaria dauci*, *Cercospora ipomoeae*, *Fusarium moniliforme*, and *Diplocarpon rosae* as clearly indicated by the diameters of the colonies. Results suggested that *K. candel* extracts possess antifungal properties and could be further processed into natural agrochemicals to be used as fungicides [43].

Antidiabetic

Plants have always been preferred for developing novel hypoglycaemic chemicals for either direct oral consumption or as simple dietary supplements to the existing anti-diabetic therapies [44, 45].

In vivo antihyperglycemic potential of the ethanol extract prepared from the *K. candel* leaves was investigated in two different male albino rat models (Sucrose loaded SL and Sucrose challenged STZ drug induced diabetic rats). Leaf ethanol extract administered at a dosage of 500 mg/kg showed a promising anti-diabetic activity in both the models at par with the standard diabetic drugs metformin and acarbose at 100 mg/kg. This extract was further partitioned and activity of the fractions was also investigated. Fractions soluble in hexane, chloroform and n-butanol did not show much activity whereas n-butanol insoluble fraction exhibited promising antihyperglycemic activity in both the rat models. The presence of polypenolic compounds (tannins and procynidins) were suggested to be responsible for the efficacy [46].

Soxhlet extracts prepared in five different solvents were tested in vitro using two different assays. Methanol extract at 100 µg concentration displayed the highest antidiabetic activity with 50.2% inhibition of α-amylase as compared to 71% inhibition shown by the standard drug acarbose. Glucose uptake inhibition experiment performed using yeast cells also confirmed the better efficacy of methanol leaf extract as compared to other extracts with 60.3% inhibition reported at a dose of 250 µg whereas 69.7% inhibition was shown by the standard drug metronidazole [47].

Dried powders of leaves and bark of *K. candel* were processed in the soxhlet apparatus to prepare chloroform, acetonitrile and water extracts. Antidiabetic activity of these crude solvent extracts (at a concentration of 500 µg/ml) was investigated by performing an *in vitro* alpha-amylase inhibitory assay. Known standard drug acarbose used for comparing the results reported 70% inhibition whereas the leaf water extract and bark acetonitrile extract exhibited promising antidiabetic activity with 50.96 and 50.32 inhibitory percentages respectively. Chloroform extracts of the leaves and bark showed significantly lower antidiabetic activity with only 9 and 11% inhibition respectively [48].

Antioxidant

Anti-oxidants are of vital importance in protecting our body cells from harmful damage caused by free radicals. Therefore new plant-based agents are being constantly screened as could lead to development of new drugs having novel therapeutic value [49 - 51].

Wei et al, analyzed antioxidant potential of hypocotyl extract prepared in acetone and also of different fractions prepared in petroleum ether, ethyl acetate, and water [37]. The purified water fraction was found to have remarkable activity followed by extract prepared in acetone. In case of DPPH radical scavenging activity, IC_{50} for purified water fraction and acetone extract was found to be 87.2 and 115.67 µg/ml respectively as compared to standard ascorbic acid (101.96 µg/ml). Ferric reducing power of the purified water fraction (5.91 mmol AAE/g) was higher than the standard BHA (5.28 mmol AAE/g). Other fractions exhibited relatively lower activity. Isolated condensed tannins from the leaves of *K. candel* showed promising DPPH radical scavenging antioxidant activity (IC_{50} of 93.51 µg/ml) and ferric reducing power (10.77 mmol AAE/g). Polyphenols present in the sample were suggested to be responsible for this activity [31].

Shettar et al, reported highly promising antioxidant capacity of leaf extracts prepared using three different solvents [27]. Percent (%) inhibition values were used to evaluate the scavenging potential of the extract. A concentration dependent inhibition was observed with methanol, ethanol, and aqueous extracts showing around 86%, 73%, and 78% inhibition at 50 µg concentration. Methanol was found to be the best solvent for extracting antioxidant principles from this plant since it showed better % inhibition than that displayed by the standard ascorbic acid (around 84%). FRAP assay also highlighted the potency/ reducing power of the methanol extract. Higher percentages of phenolic, and flavonoids detected in the methanol extracts were suggested to be responsible for this activity. Bark extracts prepared in acetonitrile (IC_{50} of 31.84 µg/ml), and water (IC_{50} 35.56 µg/ml) were found to exhibit better DPPH radical scavenging ability than the leaf extracts (IC_{50} of 187.06 and 128.23 µg/ml respectively). Antioxidant potential was further indicated by the efficient reduction of molybdenum by the acetonitrile bark extract. [48] From the results of all these studies, it has been well established that the total phenolic and flavonoid contents and antioxidant activities are positively correlated.

Anti-inflammatory

Anti-inflammatory activity of extracts prepared in methanol, ethanol and water using *K. candel* leaves collected from Western Ghats, Karnataka state, India was investigated by performing *in vitro* protein denaturation assay. Standard Diclofenac sodium as well as the plant extracts were tested at concentration of 100 µg. Results were highly encouraging and were at par with the standard for the methanol extract of *K. candel*. The methanol leaf extract demonstrated a strong anti-inflammatory activity by recording a percentage of inhibition at 96.91% which was higher than the standard drug (94.24% inhibition) and all the other extracts tested. Aqueous and ethanol leaf extracts, however, showed only 54 and 12% inhibition respectively [27].

Bone marrow-derived dendritic cells (BMDCs) are crucial mediators of innate and adaptive immune response. Activated BMDCs perform crucial functions in immune and inflammatory responses via the Pathogen-associated molecular patterns (PAMPs) recognition by pattern recognition receptors (PRRs) of BMDCs stimulate secretion of pro-inflammatory cytokines such as IL-12 p40, IL-6 and TNF-alpha. Among 19 compounds isolated from *Kandelia candel,* seven compounds exhibited potent inhibition of these three cytokines' secretion by lipopolysaccharide (LPS)-stimulated BMDCs [32]. Further these compounds were structurally characterized, six were triterpenes and two glyceryl glycosides [33].

Anticancer

Tumor necrosis factor (TNF)-related apoptosis-inducing ligand (TRAIL) is a member of the TNF superfamily and has emerged as a promising anticancer agent since it can kill cancer cells selectively. TRAIL initiates extrinsic apoptosis by binding to death receptors on surface of cancer cells viz. DR4 and DR5 and leads to assembly of death-inducing signalling complex (DISC) in the cytosol. DISC leads to proteolytic cleavage and activation of initiator caspase-8 which further cleaves and releases active tBID – pro-apoptotic protein which localizes to the mitochondria and induces intrinsic apoptosis pathway by mitochondrial membrane depolarization. Recombinant TRAIL is under clinical trials but has limitations such as short half-life, poor bioavailability etc. In addition, studies have shown that certain types of highly aggressive cancers are resistant to TRAIL, such as pancreatic adenocarcinoma and neuroblastoma. To overcome such limitations, the quest for TRAIL-inducing compounds and those which can overcome TRAIL resistance is on [52].

In the primary screening, the methanol extract of *Kandelia candel* (Rhizophoraceae) leaves was found to overcome TRAIL resistance at 100 ug/ml concentration. Minakawa et al, isolated six compounds from this extract. These compounds were shown to be able to overcome TRAIL resistance when given in combination with TRAIL (100 ng/ml 24 h) to AGC (human gastric cancer) cells. The cell viability was tested using is fluorescein diacetate stain which fluoresces green when it permeates metabolically active, viable cells [34].

Anthelmintic

Helminths are worm-like parasitic organisms that receive nourishment from their living hosts, and in the process their hosts' nutrient absorption capabilities get disrupted resulting in weakness leading to a disease. Chemical anthelmintic agents are known for a few side effects and therefore agents of natural origin are being searched.

Dried and powdered leaves of *K. candel* were subjected to soxhlet and extracts in 5 different solvents were prepared. These extracts (at 50 to 250 mg / 20 ml concentrations) were evaluated for their anthelmintic potential by recording their ability to cause paralysis and death in earthworms *Pheretima posthuma* (chosen as they resemble intestinal roundworms). All the extracts showed anthelmintic activity. Methanol extract was found to be the most lethal with a paralysis time of around 46 min and a death time of around 67 mins at 250 mg/20 ml concentration. These values were encouraging considering the extracts were crude and not purified / concentrated. Positive control Piperazine citrate used as the standard drug showed a paralysis time of around 31 min and a death time of around 36 mins at 100 mg/20 ml concentration [53].

Antifouling

One of the most common organisms that cause fouling in mangrove habitats are barnacles and therefore a few mangrove species have developed morphological and metabolic adaptations to counter settlement of barnacles. When 5 different mangrove leaves dichloromethane extracts were analyzed for anti-barnacle settlement, *K. candel* extract was found to be most effective in inhibiting the settlement of *B. albicostatus* cyprids with a mean EC_{50} value of 0.85 µg/ cm. Oleanolic acid was isolated from this extract and confirmed as the potent anti-settlement metabolite with a mean EC_{50} value of 0.06 µg/ cm suggesting its potential to be developed into a commercial anti-foulant [54]. The extract of *K. candel* has been also found to exhibit anti-settlement effect against the barnacle species *B. amphitrite* [55].

CONCLUSION

The reviewed mangrove plant *K. candel* exhibits a wide range of bioactivities such as antimicrobial, antioxidant, anti-diabetic, antifouling, anthelmintic, anti-inflammatory, anticancer etc. Having these bioactivities highlights the fact that it can have important applications in several industries, especially in pharmaceutical research and development programmes. Being plant-derived, its test products are expected to be eco-friendly and without much side effects unlike their commercial synthetic chemical counterparts. These activities are attributed to the presence of mentioned phytochemicals belonging to different chemical classes. It is therefore suggested to further explore this mangrove scientifically so that it can be exploited as a natural resource for achieving its ultimate therapeutic application.

ACKNOWLEDGEMENTS

Authors would like to express their heartfelt gratitude towards Mr. Dinesh Valke for kindly providing the permission to use his high-quality photographs of *K. candel* for educational purpose.

REFERENCES

1. Dahibhate NL, Saddhe AA, Kumar K, 2019. Mangrove plants as a source of bioactive compounds: a review. The Natural Products Journal, 9(2), Pages 86–97. Doi: 10.2174/2210315508666180910125328
2. Nabeelah Bibi S, Mahomoodally MF, Zengin G, et al, 2019. Ethnopharmacology, phytochemistry, and global distribution of Mangroves―A comprehensive review.Marine Drugs, 17(4), Pages 231. Doi: 10.3390/md17040231
3. Manohar SM, 2021. A review of the botany, phytochemistry and pharmacology of mangrove *Lumnitzera racemosa* Willd. Pharmacognosy Reviews, 15(30), Pages107–116. Doi: 10.5530/phrev.2021.15.13
4. Naskar K, Mandal R, 1999. Ecology and Biodiversity of Indian Mangroves. Daya Publishing House, Delhi, India.
5. KO W-C, 1983. Rhizophoraceae. In: Fang Wen-Pei & Chang Che-yung, eds., Flora Reipublicae Popularis Sinicae 52(2), Pages 125–143.
6. Giesen W, Wulffraat S, Zieren M, et al, 2006. Mangrove Guidebook for Southeast Asia. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand: Wetlands International, Bangkok, Thailand.
7. Tomlinson PB, 1994. The Botany of Mangroves. Cambridge University Press, Pages 1– 419.
8. Dahdouh-Guebas F (ed.) 2024. World Mangroves database. *Kandelia candel* (L.) Druce. Accessed through: World Register of Marine Species
9. *Kandelia candel* - Narrow-Leaved Kandelia (flowersofindia.net) Accessed through:
10. Minagawa M, 2000. Japan: mangrove areas and their utilization. In: Mangrove-Friendly Aquaculture, Primavera JH, Garcia LMB, Castaños MT, et al, (eds.), Proceedings of the Workshop on Mangrove-Friendly Aquaculture organized by the SEAFDEC Aquaculture Department, January 11-15, 1999, Iloilo City, Philippines, Pages 35 – 40.
11. Ray T, 2014. Customary use of mangrove tree as a folk medicine among the Sundarban resource collectors. International Journal of Research in Humanities, Arts and Literature, 2(4), Pages 43–48.
12. Sathe SS, Lavate RA, Patil SB, 2014. Ethnobotanical and medicinal aspects of mangroves from Southern Kokan (Maharashtra). International Journal of Emerging Trends in Pharmaceutical Sciences, 3(4), Pages 12–17.
13. Pattanaik C, Reddy CS, Dhal NK, et al, 2008. Utilisation of mangrove forests in Bhitarkanika wildlife sanctuary, Orissa. Indian Journal of Traditional. Knowledge, 7(4), Pages 598–603.
14. Sasidharan N, 2011. Flowering plants of Kerala, A checklist CD. Kerala Forest Research Institute, Kerala,

15. Spalding M, Kainuma M, Collins L, 2010. World Atlas of Mangroves. Earthscan, London, UK and Washington, DC, USA.

16. Malabrigo Jr. PL, Eduarte GT, Malabrigo LD, et al, 2021. *Kandelia candel* (L) Druce, a true native species in the Philippines. Philippine Journal of Science, 150(5), Pages 1121−1129.

17. Kothari MJ & Rao KM, 2002. Mangroves of Goa. Singh NP & Rao PSN (eds.), Ministry of Environment and Forests, Botanical Survey of India, Pages 1−155.

18. Dhargalkar VK, D'Souza R, Kavlekar DP, et al, 2014. Mangroves of Goa, Forest Department, Government of Goa and Mangrove Society of India, India.

19. Anonymous, 2023. Mangroves of Odisha: A pictorial guide. Mangrove Forest Division (Wildlife), Rajnagar Forest & Environment Department, Government of Odisha, Pages 1−60.

20. Das AB, Basak UC, Das P, 1995. Karyotype diversity and genomic variability in some Indian tree mangroves. Caryologia, 48(3-4), Pages 319−328. Doi: https://doi.org/10.1080/00087114.1995.10797341

21. Sheue C-R, Liu H-Y, Yong JWH, 2003. *Kandelia obovata* (Rhizophoraceae), a new mangrove species from Eastern Asia. Taxon, 52(2), Pages 287−294. Doi: https://doi.org/10.2307/3647398

22. Baba S, Chan HT, Aksornkoae S, 2013. Useful Products from Mangrove and other Coastal Plants. ISME Mangrove Educational Book Series No. 3. International Society for Mangrove Ecosystems (ISME), Okinawa, Japan, and International Tropical Timber Organization (ITTO), Yokohama, Japan, Pages 1−99.

23. Tri NH, Hong PN, Adger WN, et al, 2001. Mangrove conservation and restoration for enhanced resilience. Managing for Healthy Ecosystems. In: Living with Environmental Change. Adger WN, Kelly PM, Ninh NH, et al, (eds.), Routledge, CRC Press, USA, Pages 136-153.

24. Kirtikar KR & Basu BD, 1935. Indian Medicinal Plants. Lalit Mohan Basu Publication.

25. Tam NFY, 2004. Conservation and uses of mangroves in Hong Kong and Mainland China. In: Developments in Ecosystems. Vo. 1, Wetlands Ecosystems in Asia, Wong M. H. (ed.), Elsevier, Pages 161−182. Doi: 10.1016/S1572-7785(04)01011-1.

26. Jasna TK, Khaleel KM, 2020. GC-MS analysis of bioactive components of *Kandelia candel* (L.) Druce. Journal of Advanced Scientific Research, 11(4) Suppl 9, Pages 193−197.

27. Shettar AK, Madagi SB, Hoskeri JH, et al, 2018. Phytochemical profiling, in-vitro antioxidant and anti-inflammatory activities of *Hopea ponga*, *Kandelia candel*, *Vitex leucoxylon* and *Rhizophora apiculata*. Journal of Pharmacognosy and Phytochemistry, 7(6), Pages 1425−1440.

28. Nebula M, 2014. Bioactive metabolites and biomarkers from Rhizophoraceae mangroves – A chemotaxonomic approach. Ph. D. thesis, Cochin University of Science & Technology, Kerala, India.

29. Mfilinge P, Atta N, Tsuchiya M, 2002. Nutrient dynamics and leaf litter decomposition in a subtropical mangrove forest at Oura Bay, Okinawa, Japan. Trees, 16(2-3), Pages 172−180. Doi: https://doi.org/10.1007/s00468-001-0156-0

30. Hsu F, Nonaka G, Nishioka I, 1985. Tannins and related compounds. XXXI. Isolation and characterization of proanthocyanidins in *Kandelia candel* (L.) Druce. Chemical and Pharmaceutical Bulletin, 33(8), Pages 3142−3152. Doi: https://doi.org/10.1248/cpb.33.3142.

31. Zhang L-L, Lin Y-M, Zhou H-C, et al, 2010. Condensed Tannins from mangrove species *Kandelia candel* and *Rhizophora mangle* and their antioxidant activity. Molecules, 15, Pages 420−431. Doi: 10.3390/molecules15010420.

32. Dat LD, Thao NP, Tai BH, et al, 2015. Anti-inflammatory Triterpenes and Glyceryl Glycosides from *Kandelia candel* (L.) Druce. Natural Product Sciences, 21(3), Pages150−154.

33. Dat LD, Thao NP, Tai BH, et al, 2015. Chemical constituents from *Kandelia candel* with their inhibitory effects on pro-inflammatory cytokines production in LPS-stimulated bone marrow-derived dendritic cells (BMDCs). Bioorganic and Medicinal Chemistry Letters, 25(7), Pages 1412−1416. Doi: 10.1016/j.bmcl.2015.02.048.

34. Minakawa T, Toume K, Arai MA, et al, 2012. Eudesmane-type sesquiterpenoid and guaianolides from *Kandelia candel* in a screening program for compounds to overcome TRAIL resistance. Journal of Natural Products, 75(8), Pages 1431−1435. Doi: 10.1021/np300179c.

35. Oku H, Baba S, Koga H, et al, 2003. Lipid composition of mangrove and its relevance to salt tolerance. Journal of Plant Research, 116(1), Pages 37− 45. Doi: 10.1007/s10265-002-0069-z.

36. Basyuni M, Baba S, Oku H, et al, 2019. Difference triterpenoid and phytosterol profile between *Kandelia candel* and *K. obovata*. In: Proceedings of the International Conference on Natural Resources and Technology (ICONART 2019), Pages 51−54. Doi: 10.5220/0008505400510054.

37. Wei SD, Zhou HC, Lin YM, 2010. Antioxidant activities of extract and fractions from the hypocotyls of the mangrove plant *Kandelia candel*. International Journal of Molecular Sciences, 11(10), Pages 4080−4093. Doi: 10.3390/ijms11104080.

38. Zhang L, Xu M, Guan Q, et al, 2023. Determination of vegetable tannins from plants in China. Biofules, Bioproducts, Biorefining, 17(3), Pages 592−601. Doi: https://doi.org/10.1002/bbb.2467

39. Azuma H, Toyota M, Asakawa Y, et al, 2002. Floral scent chemistry of mangrove plants. Journal of Plant Research, 115, Pages 47−53. Doi: 10.1007/s102650200007.

40. Cowan MM, 1999. Plant products as antimicrobial agents. Clinical Microbiology Reviews, 12(4), Pages 564−582. Doi: 10.1128/CMR.12.4.564.

41. Porras G, Chassagne F, Lyles JT, et al, 2021. Ethnobotany and the role of plant natural products in antibiotic drug discovery. Chemical Reviews, 121(6), Pages 3495−3560. Doi: 10.1021/acs.chemrev.0c00922.

42. Jasna TK, Khaleel KM, Rajina M, 2017. In vitro antibacterial activity of mangrove plant *Kandelia candel* (L.) Druce (Rhizophoraceae). World Journal of Pharmaceutical Research, 6(11), Pages 470−477.

43. So ML, 1990. Antifungal activities of mangrove plants. In: Proceedings of the 3rd International conference on Plant Protection in the Tropics: Vol. 2, Malaysian Plant Protection Society, Genting Highlands, Malaysia, Pages 95−98.

44. Bhat M, Zinjarde SS, Bhargava SY, et al, 2011. Antidiabetic Indian plants: a good source of potent amylase inhibitors. Evidence Based Complementary and Alternative. Medicine, 2011, Page 810207. Doi: 10.1093/ecam/nen040.

45. Omale S, Amagon KI, Johnson TO, et al, 2023. A systematic analysis of anti-diabetic medicinal plants from cells to clinical trials. Peer J, 11, Page e14639. Doi: 10.7717/peerj.14639.

46. Lakshmi V, Kumar R, Srivastava AK, 2013. Antidiabetic effect of the leaves of *Kandelia candel* Linn. Natural Products- an Indian Journal, 9(8), Pages 319−321.

47. Shettar AK, Vedamurthy AB, 2017. Evaluation of antidiabetic potential of *Kandelia candel* and *Rhizophora apiculata* – an in vitro approach. International Journal of Pharmaceutical Sciences and Research, 8(6), Pages 2551−2559. Doi: http://dx.doi.org/10.13040/IJPSR.0975-8232.8 (6).2551-59

48. Jasna TK, Khaleel KM, 2022. Evaluation of antioxidant activities and quantitative estimation of phytochemicals in *Kandelia candel* (L.) Druce. International Journal of Research in Pharmaceutical Sciences, 13(2), Pages 166−172. Doi: https://ijrps.com/home/article/view/138/448

49. Kasote DM, Katyare SS, Hegde MV, et al, 2015. Significance of antioxidant potential of plants and its relevance to therapeutic applications. International Journal of Biological Sciences, 11(8), Pages 982−991. Doi: 10.7150/ijbs.12096.

50. Lourenço SC, Moldão-Martins M, Alves VD, 2019. Antioxidants of natural plant origins: from sources to food industry applications. Molecules, 201924(22), Page 4132. Doi: 10.3390/molecules24224132.

51. Kulkarnii CP & Manohar SM, 2024. A review of botany, phytochemistry and pharmacology of the mangrove apple *Sonneratia alba* J. Sm. Journal of Applied Pharmaceutical Sciences, 14(5), Pages 1−11. Doi: 10.7324JAPS.2024.181289.

52. Mérino D, Lalaoui N, Morizot A, et al, 2007. TRAIL in cancer therapy: present and future challenges. Expert Opinion on Therapeutic Targets, 11(10), Pages1299−314. Doi: 10.1517/14728222.11.10.1299.

53. Shettar AK & Vedamurthy AB, 2017. An in-vitro approach for evaluating anthelmintic activity of *Kandelia candel* and *Rhizophora apiculata*. Journal of Pharmacognosy and Phytochemistry, 6(1), Pages 05−09.

54. Feng D-q, Wang W, Wang X, et al, 2016. Low barnacle fouling on leaves of the mangrove plant *Sonneratia apetala* and possible anti-barnacle defense strategies. Marine Ecology Progress Series, 544, Pages 169–182.

55. Deepa S, Srikumar M, Padmakumar K, 2014. Antifouling potentials of selected mangroves from Indian Coast. Int. Journal of Natural Products Research, 4(2), Pages 54−57.