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Bioprospecting of Mangroves under Rhizophoraceae in the Indian Sundarbans for Antidiabetic Compounds: An Insight into Traditional Healthcare

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ABSTRACT:

Mangrove forest in Sundarbans is not just a marvel of nature, but also plays a major role in maintaining our natural environment and supporting the diverse wildlife within this mangrove ecosystem. Sundarbans, a UNESCO World Heritage Site (since 2019, it has been a Ramsar wetland), has got its name due to the abundance of 'Sundri' trees (*Heritiera fomes*) that is evidenced as one of antidiabetic mangrove medicinal plants. Mangrove ecosystem of Indian Sundarbans has many potential species which are used by the coastal communities since long past for curing their health ailments as supported by the regular uses to treat diabetes, gastrointestinal disorders, anti-inflammation, hepatic disorders, anticancer, nerve disorder and skin diseases etc.

In recent times, the diabetes, a serious physiological disorder all over the world, occur due to the relative or complete deficiency of insulin in the body, characterized by an abnormally high blood glucose level. India has a rich traditional knowledge on plant-based drug formulations that are protective and curative for many health ailments. The Rhizophoraceae family (true mangroves, including *Bruguiera, Rhizophora, Ceriops* and *Kandelia*) is considered of great importance in antidiabetic medicinal plant research because of several interlinked reasons. Different bioactive compounds (alkaloids, flavonoids, tannins, terpenoids) produced by these medicinal mangroves have antioxidant, anti-inflammatory, antibacterial, and anticancer activities and other health-care potentials. Extracts from these species show strong inhibition of α-glucosidase and α-amylase *in vitro*. Such enzyme-targeted mechanism is a cornerstone of modern antidiabetic therapy. Focusing on the roles of the plants of the family Rhizophoraceae in local healthcare

practices, this article tries to combine traditional wisdom with current scientific insights that hold great potential for pharmaceutical advancements as well as new drug discovery against diabetes, silent health killer disease to human.

Keywords: Bioprospecting, Sundarbans, mangroves, traditional, medicine, antidiabetic, compounds.

INTRODUCTION:

The Indian Sundarbans, extending across India and Bangladesh, represents an extensive mangrove ecosystem where freshwater rivers converge with saline tidal waters. This dynamic interaction fosters exceptional biodiversity, making the region one of the most ecologically rich and diverse habitats globally [1, 2]. Indian Sundarbans encompasses 19 Coastal Developmental Blocks (CDBs), comprising 13 within the district of South 24 Parganas and 6 within North 24 Parganas, West Bengal (Table 1, Figure 1). From a demographic standpoint, the region sustains an overwhelmingly rural population of approximately 4.37 million, with an exceptionally high density of 957 individuals per sq. km [3, 4]. Livelihoods are largely dependent upon subsistence-based coastal agriculture and capture fisheries. The vulnerability of these communities is accentuated by chronic resource scarcity, persistent poverty, and spatial remoteness. Notably, an estimated 43.5% of the population subsists below the nationally defined poverty line. Mangrove forests are among the most biologically diverse ecosystems on Earth. Lifestyle in the Sundarbans critically depends on mangrove plants for livelihood, food, housing, and medicine, as the region's economy and community culture are deeply intertwined with the mangrove forest resources. Mangrove species grow in tropical and subtropical coastal regions with saline or brackish water, such as tidal rivers and estuaries, where they can tolerate low-oxygen, muddy soils and fluctuating water levels. No other wild species exhibit such physiological and morphological adaptations to the extreme conditions. The worldwide diversity of mangrove flora includes around 81 tree and shrub species of 30 genera from 17 families. Of these, Indian mangroves represent 46 true mangrove species (42 species and 4 natural hybrids) belonging to 14 families and 22 genera [5]. Medicinal plants are considered as one of the major bio-resources for their immense therapeutics values against all kinds of common to vital human diseases related to digestive, endocrine, respiratory, nervous, urinary, and reproductive system [6]. Medical science recognizes three major forms of diabetes. Diabetes mellitus (DM), the most widespread type, arises from insufficient insulin secretion by pancreatic β-cells, leading to persistent hyperglycemia [7, 8]. Diabetes insipidus (DI), though rare, is caused by impaired production or function of antidiuretic hormone (ADH), resulting in abnormal fluid imbalance and polyuria. A third form, gastrointestinal diabetes mellitus (GDM), commonly develops during pregnancy, where hormonal changes induce temporary glucose intolerance [9]. Despite their distinct etiologies, all forms pose significant health risks; however, advances in pharmacological strategies over recent decades have markedly improved disease management. So, to cope up with different diseases in question with livelihood, most people who live at Sundarbans, the forest is more than just nature—it is a part of their daily lives and traditions. Generations of local communities have learned to use mangrove plants as natural medicine, relying on them to treat various ailments. In fact, such traditional knowledge isn't limited to the Sundarbans alone also across the world, mangrove plants have been part of folk medicine, especially in managing diseases like diabetes that is aggravating day to day [10].

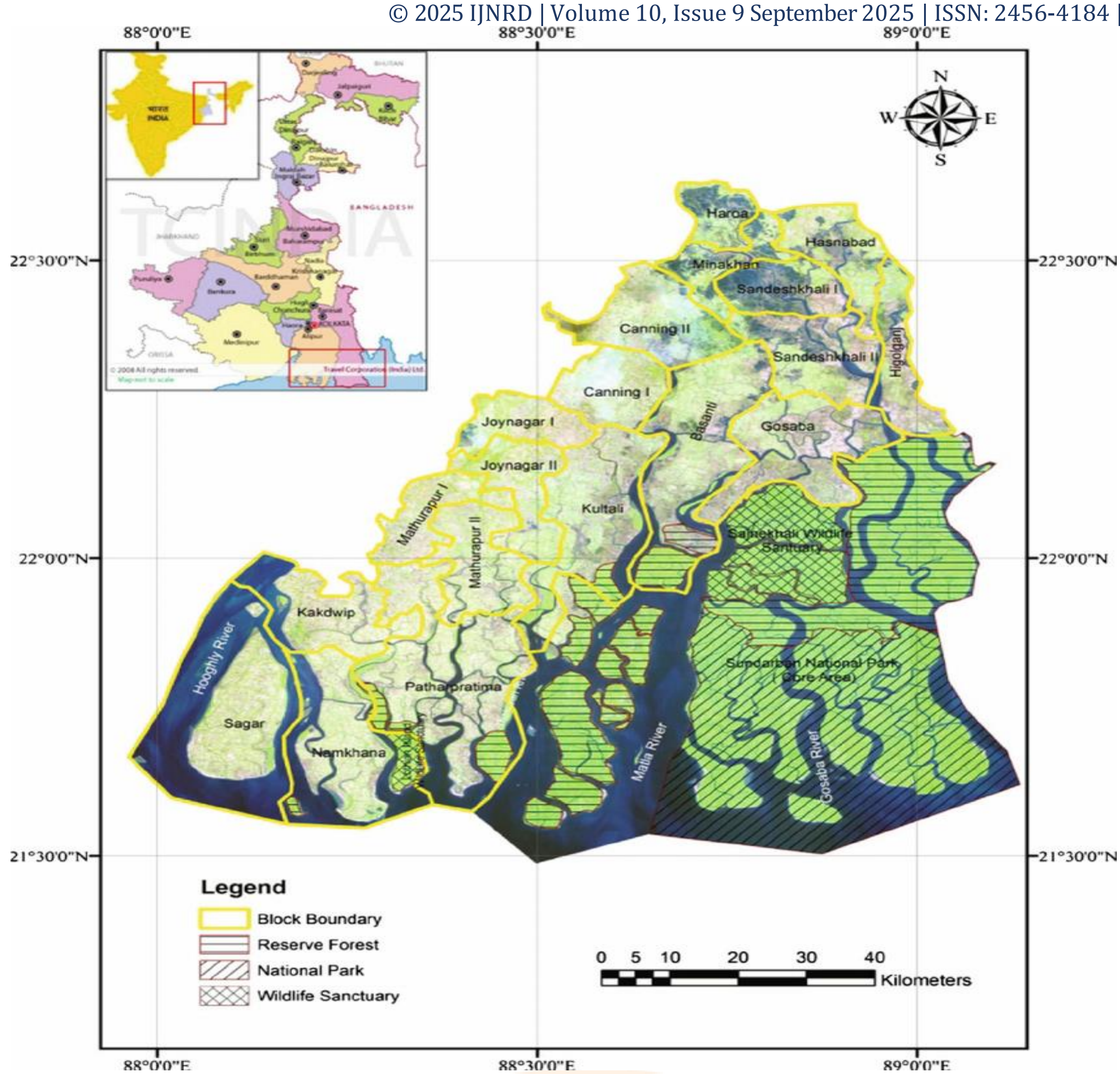


Figure-1: Location map of Indian Sundarbans; Courtsey: DasGupta *et al*. [4]

Nearly 420 medicinal plants, containing bioactive compounds such as flavonoids, glycosides, alkaloids, carotenoids, polyphenols, terpenoids, tannins etc. have been explored in treating diabetes mellitus (DM) [11, 12]. A WHO report (2016) highlighted the seriousness of this disease, noting that about 400 million people were affected worldwide and around 1.6 million deaths were linked to diabetes in 2015. WHO projected that, the number of diabetes cases could reach 300 million globally by 2025 [13]. The situation is particularly concerning in India, where diabetes has rapidly increased and now shows characteristics of a pandemic. Globally too, diabetes has become a major public health challenge. Studies suggest that India (31.7%), China (20.8%), and the USA (17.7%) are among the countries with the highest risks, and by 2030, these three nations are expected to account for the largest diabetic populations [14]. Therefore, conservation and proper utilization of mangrove medicinal plants within Indian Sundarbans eco-regions should be managed for long term benefits. Although many drugs are available to manage diabetes, long-term use often leads to side effects. For this reason, researchers are increasingly turning to natural remedies as safer alternatives to control the disease [15].

Table-1: **Names of 19 Coastal Developmental Blocks (CDB) in Indian Sundarbans under territory of West Bengal**

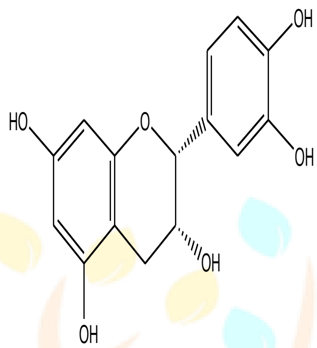
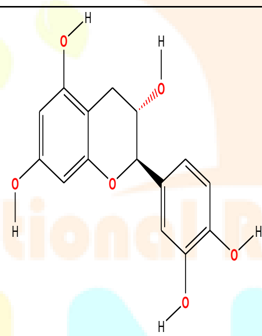
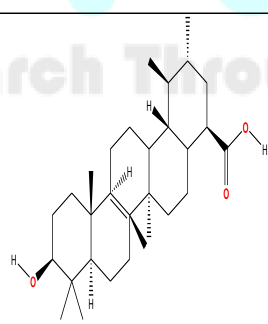
Coastal Developmental Blocks (CBDs measuring Area in Sq. Km)
Blocks (13 in no.) in South 24 Parganas: Joynagar-I (131.01), Joynagar-II (186.25), Kultali (306.18), Mathurapur-I (147.30), Mathurapur-II (227.45), Kakdwip (252.74), Sagar (282.11), Namkhana (370.61), Prathar Pratima (484.47), Canning-I (187.86), Canning-II (214.93), Gosaba (296.73), Basanti (404.21)
Blocks (6 in no.) in North 24 Parganas: Hingolgang (238.82), Hasnabad (153.07), Sandeshkhali-I (182.31), Sandeshkhali-II (197.21), Minakhan (158.82), Haroa (152.73)

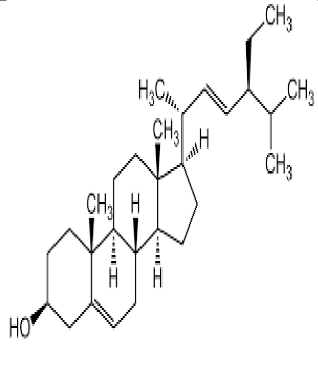
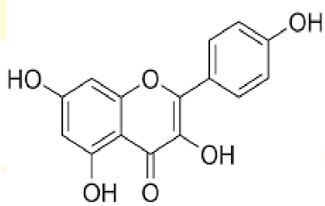
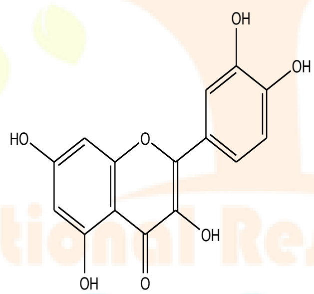
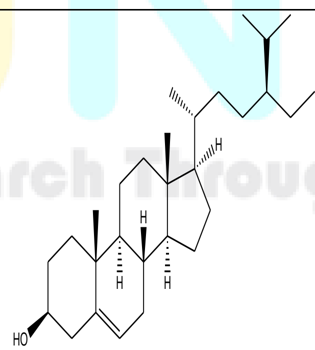
Recently, treatment options against diabetes include insulin as well as several classes of synthetic drugs, such as insulin secretagogues, insulin sensitizers, α-glucosidase inhibitors, peptide analogues, dipeptidyl peptidase-4 inhibitors, and glucagon-like peptide-1 agonists. While these medications are effective in lowering blood sugar, they are also linked to complications like hypoglycemia, weight gain, gastrointestinal problems, nausea, diarrhea, liver damage, jaundice, and in some cases, heart failure [16]. Therefore, this makes it clear that developing alternative, safer treatment strategies is an urgent need.

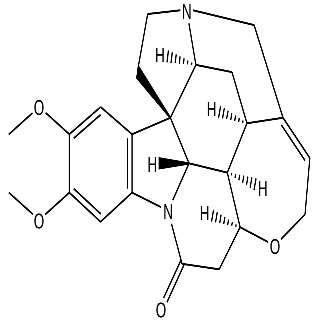
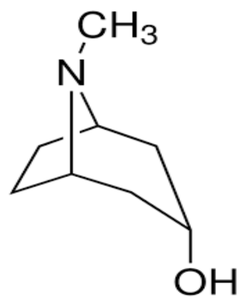
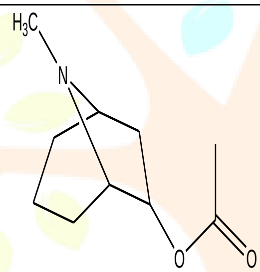
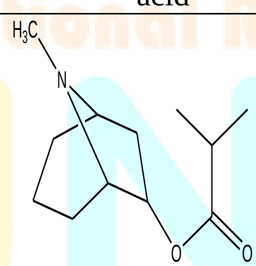
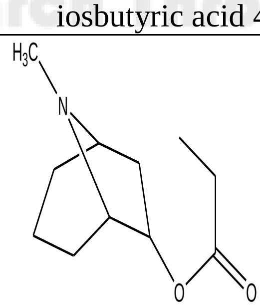
MATERIALS AND METHODS:

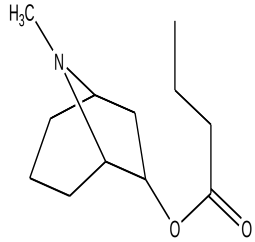
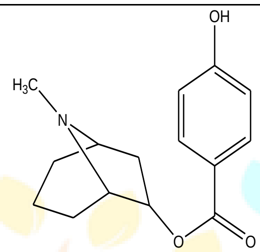
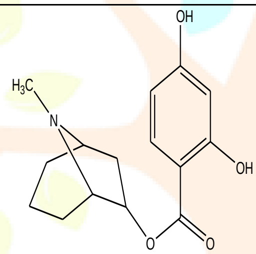
The present study is based on extensive information collected by questionaries and interviews from local communities during visits in different Costal Development Blocks of Indian Sudarbans at various times since 2022. Questionnaires were prepared in the local language and information was collected. This study is very important to know the real deal of medicinal plants and how the local people are identifying these plants. Most of the informants identified plants and explained their vernacular names. For further authentication reliability and publication purposes, the information is translated into English. After the interview, informants identified the plants taking photographs at the spot. The medicinal data were recorded in alphabetical order including family name, vernacular name, plant parts used, mode of administration, and treatment diseases etc. Literature survey was also reviewed from both library resources and online databases such as Google, Google Scholar, PubMed, ScienceDirect, and Research Gate, published research papers, reports, and articles to correlate the included current knowledge and recent scientific developments on these medicinal plants with antidiabetic potential.

Table-2: **Some important of Rhizophoraceae Mangroves in Indian Sundarbans under territory of West Bengal** [‘Common name’/ *Sc. Name;* Family; Chemical structure of Bioactive compound; Description and Reference(s)]

Srl No.	**‘Common name’& *Sc. Name***	**Family**	**Chemical structure** (Bioactive molecules acting as antihyperglycemic agents and / other functions)	**Description**	**Reference**
1.	**Garjan**’/ *Rhizophora. apiculata* ‘**Kankra**’ (Champa, Bakul, Lal)/ *Bruguiera sexangula, B. parviflora, B. gymnorrhiza.*	Rhizophoraceae	 Epicatechin	**Source**: *R. apiculata* (stem, bark, and fruits); **Mol. for**: $C_{15}H_{14}O_6$. **Mol. wt**: 290.27 **Biological activity**: *antidiabetic* (by stimulating insulin release, enhancing glucose uptake, and decreasing the activity of *dipeptidyl peptidase IV* or DPP-IV enzyme in type-2 diabetes), antioxidant	Ansari P *et al.* [15] Kim *et al.* [17] Bisht *et al.* [18] Kreft *et al.* [19]
2.	‘**Garjan**’/ *Rhizophora. apiculata* ‘**Kankra**’ (Champa, Bakul, Lal)/ *Bruguiera sexangula, B. parviflora, B. gymnorrhiza.*	Rhizophoraceae	 Catechin	**Source**: *R. apiculata* (stem, bark, leaf and fruits). **Mol. for**: $C_{15}H_{14}O_6$ **Mol. wt**: 290.26 **Biological activity**: *antidiabetic*	Ansari P *et al.* [15] Kim *et al.* [17] Bisht *et al.* [18] Kreft *et al.* [19] Nebula *et al.* [20]
3.	‘**Kankra**’ (Lal, Champa)/ *Bruguiera gymnorrhiza, B. sexangula,*	Rhizophoraceae	 Ursolic acid	**Source**: *B. gymnorrhiza, B. sexangular* (stem, bark and fruits). **Mol. for**: $C_{29}H_{48}O$ **Mol. wt**: 412.69 **Biological activity**: *antidiabetic*, antioxidant, antihyperlipidemic, antihyperglycemic.	Nebula *et al.* [20] Soodabeh *et al.* [21]

4.	'**Kankra**' (Lal, Champa)/ *Bruguiera gymnorrhiza*, *B. sexangula*	Rhizophoraceae	 Stigmasterol	**Source**: *B. gymnorrhiza*, *B. sexangular* (stem, bark and fruits). **Mol. for**: $C_{29}H_{48}O$ **Mol. wt**: 412.69 **Biological activity**: *antidiabetic*, antioxidant, antihyperlipidemic, antihyperglycemic.	Nebula *et al.* [20] Soodabeh *et al.* [21]
5.	'**Garjan**'/ *Rhizophora. apiculata* '**Kankra**' (Champa)/ *B. sexangula*,	Rhizophoraceae	 Kampherol	**Source:** *R. apiculata*, *B. sexangula* **Mol. for**: $C_{15}H_{10}O6$ **Mol. wt:** 286.239 **Biological activity:** *antidiabetic* and antiatherosclerotic	Kim *et al.* [17] Bisht *et al.* [18] Nebula *et al.* [20]
6.	'**Kankra**' (Champa)/ *B. sexangula*, '**Garjan**'/ *Rhizophora. apiculata*	Rhizophoraceae	 Quercetin	**Source:** *B. sexangula*, *R. apiculata* **Mol. for:** $C_{15}H_{10}O_7$ **Mol. wt:** 302.238 **Biological activity:** *antidiabetic*, antibacterial, antifungal, antiretroviral, antiviral	Kim *et al.* [17] Bisht *et al.* [18] Nebula *et al.* [20] Kreft *et al.* [19]
7.	'**Kankra**' (Lal, Champa)/ *Bruguiera gymnorrhiza*, *B. sexangula*	Rhizophoraceae	 beta-sitosterol	**Source**: *B. gymnorrhiza*, *B. sexangular* **Mol. for**: $C_{29}H_{50}O$ **Mol. wt**: 414.71 **Biological activity**: *antidiabetic*	Kim *et al.* [17] Bisht *et al.* [18] Nebula *et al.* [20] Kreft *et al.* [19]

8.	**'Kankra'** (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Brucine	**Source**: *B. sexangula* (stem and bark) **Mol for**: $C_{12}H_{19}NO_2S_2$ **Mol. wt**: 273.409 **Biological activity**: *antidiabetic*, anticancer	Nebula *et al.* [20] Richter *et al.* [21] Loder and Russell [22]
9.	**'Kankra'** (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine	**Source**: *B. sexangula* (stem and bark) **Mol. for**: $C_8H_{15}NO$ **Mol. wt**: 141.214 **Biological activity**: *antidiabetic*	Loder and Russell [22] Brion *et al.* [23]
10.	**'Kankra'** (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine esters of acetic acid	**Source**: *B. sexangula* (stem and bark) **Mol. for**: $C_{10}H_{17}NO_2$ **Mol. wt**: 183.25 **Biological activity**: *antidiabetic*, anticancer, antiemetic	Loder and Russell [22] Brion *et al.* [23]
11.	**'Kankra'** (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine esters of iosbutyric acid 4	**Source**: *B. sexangula* (stem and bark) **Mol for**: $C_{12}H_2NO_2$ **Mol. wt**: 211.31 **Biological activity**: *antidiabetic*, anticancer, antiemetic	Loder and Russell [22] Brion *et al.* [23]
12.	**'Kankra'** (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine esters of propionic acid 6	**Source**: *B. sexangula* (stem and bark) **Mol for**: $C_{11}H_{19}NO_2$ Mol. wt: 197.28 **Biological activity**: *antidiabetic*, anticancer, antiemetic	Loder and Russell [22] Brion *et al.* [23]

13.	'**Kankra**' (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine esters of n-butyric acid	**Source**: *B. sexangular* (stem and bark) **Mol for**: $C_{12}H_{21}NO_2$ **Mol. wt**: 211.31 **Biological activity**: *antidiabetic*, anticancer, antiemetic	Loder and Russell [22] Brion *et al.* [23]
14.	'**Kankra**' (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine esters of 4-hydroybenzoic acid	**Source**: *B. sexangular* (stem and bark) **Mol. For**: $C_{15}H_{19}NO_3$ **Mol. wt**: 261.32 **Biological activity**: *antidiabetic*, anticancer, antiemetic	Loder and Russell [22] Brion *et al.* [23]
15.	'**Kankra**' (Champa)/ *Bruguiera sexangula*	Rhizophoraceae	 Tropine esters of ethyl 3,4-dihydroxybenzoate	**Source**: *B. sexangular* (stem and bark) **Mol. For**: $C_{16}H_{21}NO_5$ **Mol. wt**: 307.35 **Biological activity**: *antidiabetic*, anticancer, antiemetic	Loder and Russell [22] Brion *et al.* [23] Gronkiewiz and Gadzikowsa [24]

Studies on Antidiabetic Activities of Mangroves Plants from Indian Sundarbans:

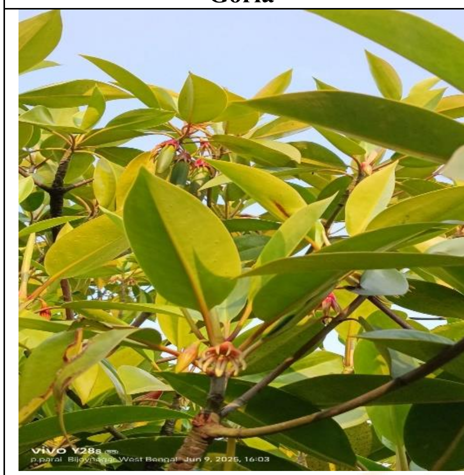
Antidiabetic Activity of Mangrove Extracts and Their Phytochemicals

Mangrove plants, thriving in saline and stressful coastal ecosystems, are recognized as a rich source of bioactive compounds with significant antidiabetic potential. Globally, more than 400 plant species and their metabolites—including glycosides, alkaloids, terpenoids, flavonoids, carotenoids, tannins, polyphenols, fatty acids, and steroid derivatives—are employed in diabetes management. Notably, mangroves are considered effective and relatively free of side effects, with Asia harboring the greatest species diversity (44 species). Their phytochemical constituents and associated mechanisms of antidiabetic action have been systematically documented.

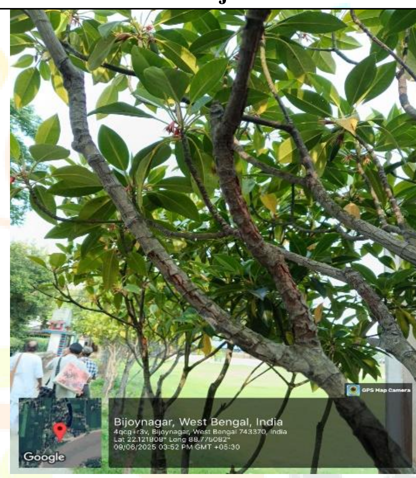
Candelia canden
'Goria'

Rhizophora apiculata
'Garjan'

Rhizophora mucronata
'Bara Goran'

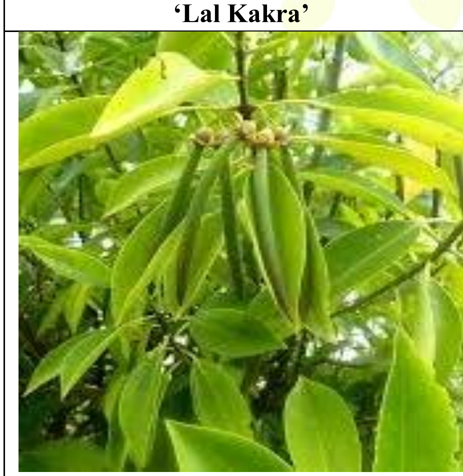


Bruguiera gymnorrhiza
'Lal Kakra'



Bruguiera sexangula
'Champa Kakra'

Bruguiera parviflora
'Bakul Kakra'



Bruguiera cylindrica
'Sona Champa'

Ceriops decadra
'Jele Goran'

Ceriops tagal
'Math Goran'

Figure-2: Some antidiabetic mangrove plants of the family Rhizophoraceae found in the Indian Sundarbans, West Bengal.

○ **<u>Antidiabetic potential mangrove species of Rhizophoraceae</u>:**

The family Rhizophoraceae is represented in Indian mangroves by the genera *Bruguiera, Kandelia, Ceriops* and *Rhizophora*. Several species within these genera exhibit potent antidiabetic properties, supported by experimental evidence using animal models already reported [20, 21, 22]. In the Indian Sundarbans of West Bengal, where mangrove biodiversity is especially very rich, these plants have been traditionally recognized from earlier period and are now scientifically validated for their pharmacological role in managing diabetes.

			
Mangroves plants (Rhizophoraceae) infested with high-rise of tidal water where pneumatophores are waterlogged.	*Rhizophora* (*R. mucronata*) Avenue of Bijoynagar Adarsha Vidyamandir (BAV), Bali, Sundarban, W.B. (Survey leaded by Sukumar Paira, Ex-headmaster, BAV).	Person (Sukumar Paira, Ex-headmaster, BAV, won Green Teacher Award, 2007) who transformed the Sundarban into new Green Nature specially Bali Island.	A student of Bijoynagar Adarsha Vidyamandir (BAV), Bali, demonstrating us edible part of a mangrove antidiabetic plant during a study.

Figure-3: photographs of different perspectives during the recent field study (2025)

- ***Bruguiera* Species**

Globally, six species of *Bruguiera* are reported, of which four (*B. gymnorrhiza*, *B. cylindrica, B. parviflora*, and *B. sexangula*) occur in India. *B. gymnorrhiza*, widely distributed in the Sundarbans, has been extensively studied for its antidiabetic potential. Ethanol extracts of its bark demonstrated significant antihyperglycemic effects in streptozotocin (STZ)-induced diabetic rats, with a 400 mg/kg dose reducing blood glucose levels comparably to glibenclamide (0.5 mg/kg) [25]. The extract also improved lipid profiles, lowering total cholesterol, triglycerides, very-low-density lipoprotein (VLDL), and low-density lipoprotein (LDL), while elevating high-density lipoprotein (HDL). Phytochemicals such as bruguierol, β-sitosterol, α-/β-amyrin, lupeol, oleanolic acid, ursolic acid, taraxerol, gymnorhizol, and ellagic acid have been identified as the bioactive constituents contributing to this effect. It is studied that ethanolic bark extract lowers blood glucose; improves lipid profile; antihyperglycemic via insulin-mimetic compounds.

Table-3: Antidiabetic Mangrove Plants of the Family Rhizophoraceae in Indian Sundarbans

The following table presents a comparative overview of mangrove plants of the family Rhizophoraceae that are found in the Indian Sundarbans, West Bengal. The table summarizes their species, active plant parts, identified bioactive compounds, mechanisms of antidiabetic action, and supporting references.

'Loal name' & Sc . name (Species)	Active Plant Part	Bioactive Compounds	Mechanism of Antidiabetic Action	References
Bruguiera gymnorrhiza	Bark	Bruguierol, β-sitosterol, α-/β-amyrin, lupeol, oleanolic acid, ursolic acid, taraxerol, gymnorhizol, ellagic acid	Ethanolic bark extract lowers blood glucose; improves lipid profile; antihyperglycemic via insulin-mimetic compounds	[25]
Ceriops decandra	Leaves	Phenolic compounds, flavonoids	Enhances insulin secretion; regulates hexokinase, glucose-6-phosphatase, fructose-1,6-bisphosphatase; improves HbA1c	[26]
Ceriops tagal	Leaves, Bark	Unique compounds (hexane fraction), phenolics	Inhibits PTP*ase* enzyme; stimulates glucose uptake in muscle cells; α-glucosidase inhibition; improves glucose tolerance	[27, 28]
Rhizophora apiculata	Roots, Leaves	Lupeol, oleanolic acid, β-sitosterol, palmitic acid, inositol, pinitol, flavonoids	Antihyperglycemic via insulin-like protein activity; antioxidant and β-cell protective effect	[29, 30]
Rhizophora mucronata	Bark, Leaves	Phenolics, flavonoids (unspecified)	Hypoglycemic via inhibition of carbohydrate digestion and glucose absorption; α-glucosidase inhibition	[31, 32, 33]
'Goria/Guria' *Kandelia candel*	Bark, Leaves	Polyphenols (flavonoids, tannins, phenolic acids)	Hypoglycemic via inhibition of carbohydrate digestion and glucose absorption; α-glucosidase and α-amylase inhibition	[34]

- ***Ceriops* Species**

Two species of *Ceriops*, namely *C. decandra* and *C. tagal*, are common in Indian mangroves and both are present in the Sundarbans. Ethanolic leaf extract of *C. decandra* (120 mg/kg) significantly reduced serum glucose levels in alloxan-induced diabetic mice, with results comparable to glibenclamide (0.1 mg/kg bw) [35]. The extract enhanced insulin secretion, improved body weight, normalized hemoglobin A1c (HbA1c) levels, and modulated key enzymes of glucose metabolism including hexokinase, glucose-6-phosphatase, and fructose-1,6-bisphosphatase. Similarly, *C. tagal* leaf extracts showed hypoglycemic effects in STZ-induced diabetic rats at 250 mg/kg. Its hexane fraction (100 mg/kg) was especially effective, acting through protein tyrosine phosphatase (*PTPase)* inhibition, stimulation of glucose uptake in L6 muscle cells and α-glucosidase inhibition [31]. These findings highlight the multifaceted mechanisms of *Ceriops* species in regulating hyperglycemia.

- ***Rhizophora* Species**

Among the genus *Rhizophora*, three species—*R. apiculata* and *R. mucronata*—have been reported for antidiabetic activity [29]. In the Sundarbans, *R. apiculata* and *R. mucronata* are particularly common. Ethanolic root extracts of *R. apiculata* (250 mg/kg) exhibited potent antihyperglycemic activity, attributed to phytochemicals such as lupeol, oleanolic acid, β-sitosterol, palmitic acid, β-sitosterol-3-D-glucoside, inositol, and pinitol, with inositol and pinitol showing notable effects in STZ models [35]. Leaf extracts demonstrated both hypoglycemic and antihyperglycemic activities, mediated by flavonoids with antioxidant and β-cell protective properties. SDS-PAGE and ELISA analyses confirmed the presence of insulin-like proteins in *Rhizophora* extracts, further substantiating their role in glucose regulation [29].

In *R. mucronata*, aqueous bark extracts exhibited dose-dependent hypoglycemic and antihyperglycemic activity by inhibiting carbohydrate digestion and glucose absorption [32]. Its antidiabetic effect has also been linked to α-glucosidase inhibition [31], corroborating its traditional use in managing diabetes in coastal communities.

- ***Kandelia* Species**

The mangrove plant *Kandelia candel* (family Rhizophoraceae), native to the Indian Sundarbans, represents a valuable species for bioprospecting due to its diverse repertoire of bioactive compounds with significant pharmacological relevance. Phytochemical investigations have revealed that *K. candel* is rich in flavonoids (quercetin, catechin), tannins, saponins, terpenoids, alkaloids, and phenolic acids—all of which are associated with antidiabetic mechanisms such as inhibition of carbohydrate-hydrolyzing enzymes (α-amylase and α-glucosidase), enhancement of insulin secretion, improvement of glucose uptake, and reduction of oxidative stress in pancreatic β-cells. These compounds collectively contribute to maintaining glycemic control, making *K. candel* a potent natural candidate in diabetes management. Beyond its pharmacological promise, bioprospecting of *K. candel* also underscores the importance of conserving mangrove ecosystems, as they serve as reservoirs of novel therapeutic agents. By integrating traditional ethnomedicinal knowledge with modern pharmacological validation, *Kandelia candel* exemplifies how biodiversity-rich mangroves can be harnessed sustainably for the discovery of plant-derived antidiabetic drugs.

Therefore, Mangrove plants of the Rhizophoraceae family, particularly *Bruguiera gymnorrhiza, Ceriops decandra, Ceriops tagal, Rhizophora apiculata, Rhizophora mucronata and Kandelia candel* which are widely distributed in the Indian Sundarbans of West Bengal, exhibit significant antidiabetic properties. Their bioactive compounds act through diverse mechanisms including stimulation of insulin secretion, inhibition of carbohydrate-digesting enzymes, improvement of glucose uptake, antioxidant activity, and presence of insulin-like proteins. These findings highlight the potential of mangrove-derived phytochemicals as alternative therapeutic agents for diabetes management, while also emphasizing the ecological and pharmacological importance of conserving Sundarban mangroves.

Diabetes Remedies from Traditional Knowledge on Mangrove Plants:

Diabetes mellitus (DM) is a major global public health concern, with persistent hyperglycemia contributing to severe complications such as nephropathy, retinopathy, cardiovascular diseases, and amputations. In India, the therapeutic use of plants for diabetes management dates back to Charaka and Sushruta, and ethnobotanical surveys suggest that nearly 800 species may possess antidiabetic potential [36]. While terrestrial plants such as *Momordica charantia, Pterocarpus marsupium,* and *Trigonella foenum-graecum* are well documented, limited attention has been given to mangrove species. Glycosides isolated from *Lumnitzera racemosa* and *Aegiceras corniculatum* indicate possible roles in regulating blood glucose and supporting skin health. Ethnopharmacological records cite over 100 mangroves and mangrove-associated species used traditionally against diabetes, yet only a small proportion has been scientifically validated [37]. Among these, *Aegiceras corniculatum* is reported for traditional use in Southeast India [38], while leaves of *Rhizophora mucronata and Ceriops decandra* show hypoglycemic effects, with gut perfusion studies in Long-Evans rats elucidating their mechanisms [32]. Collectively, these findings highlight mangroves as an underexplored source of bioactive compounds with significant antidiabetic potential, offering promising prospects for both modern pharmacology and traditional medicine.

FUTURE PROSPECTS:

Mangrove ecosystems represent an invaluable yet underexplored source of bioactive compounds with therapeutic potential against diabetes mellitus. While ethnopharmacological surveys report that more than 100 mangrove and mangrove-associated species are traditionally used for diabetes management [34], scientific validation remains limited. Only a handful of species, such as *Rhizophora mucronata, Ceriops decandra, Aegiceras corniculatum, and Lumnitzera racemosa*, have been investigated for their hypoglycemic properties, with studies revealing glycosides and other phytochemicals that may regulate blood glucose levels. This knowledge gap highlights the urgent need for systematic and multidisciplinary research efforts.

Future studies should first focus on comprehensive phytochemical profiling of mangrove species using advanced techniques such as LC-MS, NMR spectroscopy, and metabolomics. Such approaches would allow the identification of novel compounds and the establishment of chemotaxonomic markers for bioactivity. Parallel *in vitro* studies targeting key molecular pathways—such as insulin secretion, glucose uptake, and inhibition of carbohydrate-hydrolyzing enzymes—would provide mechanistic insights into their antidiabetic actions. Promising leads could then be validated through *in vivo* animal models that closely mimic the pathophysiology of Type-2 diabetes.

A major gap in current research is the lack of clinical studies evaluating the efficacy and safety of mangrove-derived extracts or isolated compounds. Beyond pharmacological validation, there is a pressing need to consider the sustainability of mangrove resources. Overexploitation for medicinal purposes could threaten these fragile ecosystems, which already face pressures from climate change, coastal development, and pollution. Thus, strategies

such as sustainable harvesting, cultivation of mangrove species, and biotechnological approaches (e.g., plant tissue culture or microbial endophyte-based metabolite production) should be integrated into future research agendas.
Another promising direction lies in the integration of ethnopharmacological knowledge with modern computational tools. Bioinformatics and network pharmacology approaches can help predict molecular targets of mangrove-derived compounds, while artificial intelligence (AI) and machine learning may accelerate drug discovery pipelines by linking traditional usage patterns with mechanistic data.

CONCLUSION:

Mangrove and mangrove-associated plants represent a largely untapped reservoir of bioactive compounds with demonstrated antidiabetic potential. Although traditional knowledge records over 100 species used in managing diabetes, only a limited number have undergone rigorous pharmacological and mechanistic evaluation. Preliminary evidence, including the hypoglycemic effects of *Rhizophora mucronata*, *Ceriops decandra* underscores their therapeutic promise. Future research should prioritize systematic phytochemical characterization, molecular mechanism studies, and clinical validation of these species to establish their efficacy and safety. Integrating ethnopharmacological insights with modern drug discovery approaches could accelerate the development of novel, plant-based antidiabetic therapies derived from Indian mangrove ecosystm.
Finally, the therapeutic potential of mangrove plants should not be considered in isolation. Given the high prevalence of diabetes-related comorbidities, future investigations could explore their multi-target benefits, such as antioxidant, anti-inflammatory, and cardioprotective activities. This holistic perspective aligns with the traditional use of plants in polyherbal formulations and could lead to the development of multi-component nutraceuticals or functional foods.
In conclusion, mangrove plants including the most important true mangrove family, the Rhizophoraceae, present a promising frontier in antidiabetic drug discovery. By bridging traditional knowledge with modern scientific methodologies, future research can unlock their full potential while promoting both human health and ecological sustainability.

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