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Bioactive Compounds of Different Mangroves and Their Medicinal Properties: A Comprehensive Review

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ABSTRACT:

Mangroves are the intertidal coastal ecosystems identified by their salt-tolerant shrubs and trees; they are rich source of bioactive compounds with eminent medicinal properties. A wide range of phytochemicals including flavonoids, terpenoids, alkaloids, and phenolic compounds, have been isolated from various mangrove species such as Avicennia, Rhizophora, and Exocaria. These compounds, produced by mangrove plants and associated microorganisms, exhibit various biological activities that make them valuable for various applications. The bioactive compounds found in mangroves are phenolic compounds, terpenoids, flavonoids, alkaloids, and saponins. Phenolic compounds, such as flavonoids and tannins, are noted for their potent antioxidant and anti-inflammatory properties, which help mitigate oxidative stress and inflammation. These attributes make them promising candidates for developing anti-aging and anti-inflammatory therapies. Terpenoids extracted from mangroves helps in treating various diseases such as cancer diabetes, and cardiovascular conditions. Saponins known for immune boosting and anticancer properties, providing basics for developing natural immune modulators and cancer therapeutics. This review explores the diverse bioactive compounds found in mangrove plants and their potential therapeutic applications. It also addresses the challenges in extracting and utilizing these bioactive compounds, including issues related to sustainability and environmental impact.

Keywords: Bioactive compounds, Mangroves, Phenolic compounds, Saponins, Terpenoids.

1. Introduction

The mangrove forest is one of the tropical forests that store immense ecological, biological and economic benefits (Kumar S, Abhay K P 2013). It covers about 6,749 sq. km along the 7516.6 km long coastline including Indian territories (P. Saran raj et al., 2015). World largest mangrove forest is situated at Indian Sundarbans (Sarker et al., 2016). Mangroves are halophytes that act as an interface between terrestrial and marine ecosystem (Giri et al., 2011). Mangroves are coastal plants which helps in protecting the coastal region from the environmental damages (Hardoko et al., 2016; Kurniadi and koeslulati 2020). Mangroves produce secondary metabolites which are used to treat various diseases (Salini 2015). Mangroves contain bioactive compounds such as phenols, alkaloids, flavonoids, steroids and terpenoids these compounds are studied form the extract of mangroves contains toxicological and Pharmacological properties (Piyush et al., 2012; G. Eswaraiah et al., 2020). In china, mangroves used for treating various diseases such as diabetes, angia, diarrhea, dysentery, hematuria and hemorrhage (Duke and wain 1981). It has antibacterial (Chandrasekaran et al. 2009), antifungal (Bose and Bose 2008), antiviral (Premanathan et al., 1999a), and antioxidant properties (Babu et al., 2007).

2. Bioactive Compounds

A) ALKALOIDS:

Alkaloids are diverse group of natural organic compounds containing nitrogen, they found in various mangrove species and exhibit significant medicinal properties. These compounds, known for their potent biological activities, have been traditionally used in medicine and continue to attract scientific interest for their therapeutic potential. One of the prominent medicinal properties of alkaloids in mangroves is their antimicrobial activity [25]. Alkaloids which are isolated from mangrove plants have shown effectiveness against a wide range of pathogens, including bacteria, fungi, and viruses. This antimicrobial action makes them more valuable in developing new antibiotics, especially in an era where antibiotic resistance is a growing concern. Alkaloids derived from species like Rhizophora mucronata and Avicennia marina [6] have demonstrated significant antibacterial activity against common pathogens such as Escherichia coli and Staphylococcus aureus. (P.B. Abeysinghe,2010).

The anticancer potential of mangrove alkaloids is another area of significant interest [14]. Some alkaloids have been found to inhibit the growth of cancer cells and induce apoptosis, in these cells. Alkaloids in mangroves also exhibit neuroprotective and analgesic properties, which are beneficial in treating neurodegenerative diseases and pain management. Some mangrove alkaloids have been found to protect nerve cells from damage, potentially offering therapeutic options for conditions like Alzheimer's and Parkinson's diseases. Additionally, their analgesic properties also helps in relieving pain, further expanding their medicinal applications. The anti-inflammatory and antioxidant activities [31] of mangrove alkaloids contribute to their therapeutic potential in managing inflammatory diseases and reducing oxidative stress, which is linked to chronic conditions such as cardiovascular diseases and cancer. By inhibiting inflammatory pathways and neutralizing free radicals, these alkaloids help in reducing the risk of this diseases.

B) TERPENOIDS

Terpenoids, are diverse class of organic compounds, play a significant role in the ecological and physiological functions of mangrove plants. Terpenoids in mangroves exhibit medicinal properties, contributing to their potential in pharmaceutical applications. These natural compounds are known for their antimicrobial, anti-inflammatory, antioxidant, and anticancer

activities, making them valuable in traditional and modern medicine. Mangrove terpenoids, such as sesquiterpenes and diterpenes, have been found effective against a range of pathogens [10], including bacteria, fungi, and viruses. Their antioxidant properties help in scavenging free radicals, thereby reducing oxidative stress, which is linked to various chronic diseases. Some terpenoids from mangroves have shown potential in inhibiting cancer cell growth and inducing apoptosis, making them candidates for anticancer therapies. Additionally, their anti-inflammatory effects can be beneficial in treating inflammatory conditions.

C) PHENOLIC COMPOUNDS

Phenolic compounds in mangroves are vital secondary metabolites with significant ecological and medicinal importance. These compounds, including flavonoids, tannins, and phenolic acids. [15] In mangroves, phenolic compounds also play a role in adaptation to saline environments by protecting against oxidative damage. Medicinally, these compounds exhibit strong antioxidant, anti-inflammatory, antimicrobial, and anticancer properties, making them valuable for therapeutic applications. [32] For instance, flavonoids and tannins from mangroves have shown potential in treating infections and inflammatory conditions. The antioxidant activity [3] of phenolics is crucial in neutralizing free radicals, thereby reducing the risk of chronic diseases like cancer and cardiovascular disorders.

a) FLAVONOIDS

Flavonoids, a prominent class of phenolic compounds in mangroves, are gaining recognition for their diverse medicinal applications. These naturally occurring polyphenolic compounds are known for their potent antioxidant, anti-inflammatory, antimicrobial, and anticancer properties, making them valuable in both traditional and modern medicine.

The antioxidant activity of flavonoids is one of their most significant medical applications. In mangroves, flavonoids help protect the plants from oxidative stress caused by harsh environmental conditions. When used medicinally, these compounds can neutralize free radicals in the human body, reducing oxidative stress [27] and lowering the risk of chronic diseases such as cancer, cardiovascular disorders, and neurodegenerative diseases. Flavonoids in mangroves also exhibit strong anti-inflammatory effects. They inhibit the production of pro-inflammatory cytokines and enzymes, thereby reducing inflammation and its associated symptoms [6]. This makes them promising candidates for treating inflammatory diseases such as arthritis, asthma, and inflammatory bowel disease. In cancer treatment, flavonoids have shown potential by inducing apoptosis (programmed cell death) in cancer cells, inhibiting tumor growth, and preventing metastasis [21]. This highlights their potential role in developing new anticancer therapies.

b) TANNINS

Tannins in mangroves are a group of polyphenolic compounds known for their significant medicinal properties. [8] These compounds are abundant in mangrove species, where they play a crucial role in the plants' defense mechanisms, protecting them from herbivores, pathogens, and environmental stresses. Beyond their ecological functions, tannins possess a range of bioactive properties that make them valuable in medicine.

One of the most notable medical applications of tannins is their astringent property, which helps in wound healing. Tannins can precipitate proteins, leading to the formation of a protective layer over wounds, reducing bleeding and promoting faster healing. This astringency also helps in treating diarrhea by constricting tissues and reducing fluid secretion in the intestines. [13] Tannins exhibit strong antimicrobial property which inhibit the growth of bacteria, fungi, and viruses, making them effective against a variety of infections. This antimicrobial activity is particularly important in the development of natural antiseptics and

preservatives. [7]. The antioxidant property helps in neutralizing free radicals in the body, thereby reducing oxidative stress and lowering the risk of chronic diseases such as cancer and cardiovascular disorders. Their anti-inflammatory effects further contribute to their therapeutic potential, as they can reduce inflammation in conditions like arthritis and other inflammatory diseases. In addition to these tannins also exhibits anti-cancer property.

D) STEROIDS

These natural steroids are secondary metabolites produced by mangrove plants. Mangrove-derived steroids exhibit strong anti-inflammatory effects. They inhibit the production of pro-inflammatory cytokines and enzymes, making them potentially useful in treating conditions like arthritis, asthma, and other inflammatory diseases. These steroids have been found to possess antimicrobial properties, including antibacterial, antifungal, and antiviral activities [6,9]. They can be effective against various pathogens, including drug-resistant strains, making them potential candidates for developing new antibiotics. The steroids from mangroves have significant antioxidant properties, which help in neutralizing free radicals in the body. This can prevent oxidative stress-related damage, thereby protecting against chronic diseases like cancer, cardiovascular diseases, and neurodegenerative disorders. Some steroids isolated from mangroves have demonstrated cytotoxic effects on cancer cells. These compounds can induce apoptosis (programmed cell death) in cancerous cells, making them potential candidates for cancer treatment. Research suggests that mangrove steroids may help in regulating blood sugar levels, showing potential in managing diabetes. They could improve insulin sensitivity and reduce the risk of diabetes-related complications [12]. Steroids from mangroves may also aid in wound healing. Their anti-inflammatory and antimicrobial properties, combined with the ability to promote tissue regeneration, make them useful in treating wounds and skin.

E) SAPONINS

Saponins are naturally occurring compounds found in mangroves, are another class of bioactive substances with various medicinal properties. These glycosides are known for their diverse biological activities and have attracted attention for their potential therapeutic applications. Saponins have shown promising anticancer activity. Some studies suggest that saponins from mangroves can disrupt cancer cell membranes and prevent metastasis, making them potential candidates for cancer therapy. Saponins possess strong antioxidant properties, which help in neutralizing free radicals and reducing oxidative stress in the body. This is important for preventing cellular damage and protecting against chronic diseases such as cardiovascular diseases, neurodegenerative disorders, and cancer.

Saponins have significant anti-inflammatory effects. They inhibit the production of inflammatory mediators, making them useful in managing conditions like arthritis, asthma, and other inflammatory disorders. Saponins from mangroves exhibit antimicrobial properties, including antibacterial, antifungal, and antiviral activities. They can be effective against a wide range of pathogens, making them potential agents for treating infections and as alternatives to conventional antibiotics. Some saponins have shown protective effects on the liver, helping to prevent liver damage caused by toxins or diseases like hepatitis. This hepatoprotective property is valuable in treating or managing liver-related conditions [32]. Saponins can help regulate blood glucose levels and improve insulin sensitivity, making them beneficial in managing diabetes. They may also help reduce the risk of diabetes-related complications by protecting against oxidative stress and inflammation. Saponins have been found to modulate the immune system. They can enhance immune responses, which is beneficial in fighting infections and potentially in developing vaccines. Saponins have the

ability to bind to cholesterol, reducing its absorption in the intestine. This property can help in lowering blood cholesterol levels, thereby reducing the risk of cardiovascular diseases [32]. The wound healing properties of saponins are attributed to their anti-inflammatory and antimicrobial effects, as well as their ability to promote cell proliferation and tissue regeneration.

Antioxidant Activity of Mangrove Extracts

Oxidative stress, resulting from an imbalance between free radicals and antioxidants in the body, is implicated in the pathogenesis of various chronic diseases, including cancer, cardiovascular diseases, and neurodegenerative disorders. The search for natural antioxidants has intensified, leading to the exploration of various plant sources. Mangroves, with their unique adaptive mechanisms to harsh environmental conditions, have developed a rich repertoire of bioactive compounds, including potent antioxidants. This review provides an overview of the antioxidant potential of mangroves, focusing on their phytochemical composition, antioxidant activity, and potential therapeutic applications.

Numerous studies have demonstrated the antioxidant activity of mangrove extracts using various in vitro and in vivo models. These activities are primarily attributed to the high levels of phenolic compounds present in the extracts.

Antioxidants are divided into two types of natural antioxidants and synthetic antioxidants. The usage of natural antioxidants has expanded and is thought to be safer because they are derived from natural substances, as opposed to synthetic antioxidants like butylated hydroxy aniline (BHA) and butylated toluene (BHT), which have been shown to have a carcinogenic effect [34].

1. DPPH Radical Scavenging Activity: The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay is a common method used to evaluate the free radical scavenging activity of plant extracts. Mangrove extracts, particularly from Rhizophora and Bruguiera species [35] have shown significant DPPH scavenging activity, indicating their strong antioxidant potential. In Another study on the antioxidant activity of the ethanol extract of the leaves and stem bark of S. alba found that both had strong antioxidant potentials of 20.27 ppm and 18.62 ppm. The leaves of Avicennia marina show the high values in DPPH Activity on 2017 by Iranawati, F et al., [36]. The antioxidant activity of the methanol extract of Xylocarpus moluccensis bark was tested using the DPPH method. With an IC50 value of 26,189 ppm, the DPPH test on a methanol extract of Xylocarpus moluccensis bark reveals a highly reactive antioxidant. These results indicate that the methanol extract of mangrove bark has a very strong antioxidant activity with an IC50 value of<50ppm [37].

2. Ferric Reducing Antioxidant Power (FRAP): The FRAP assay measures the antioxidant effect of plant extracts in reducing ferric ions to ferrous ions. Mangrove species such as Sonneratia apetala have exhibited high FRAP values, correlating with their phenolic content by Siti Irma Rahmawati et al., [38] studied on the Sonneratia caseolaris and shows the highest FRAP activities.

3. Lipid Peroxidation Inhibition: Inhibition of lipid peroxidation is another key indicator of antioxidant activity. Mangrove extracts have been effective in preventing lipid peroxidation in various models, suggesting their potential in protecting against oxidative damage in biological membranes.

4.ABTS assay (2,2-Azinobis -3-ethylbenzothiazoline-6-sulphonic acid): In 2011 Krishnamoorthy, Metal., studied on the bark of Bruguiera cylindrical which showed the

ABTS high values [39]. In 2017 Bidve, SC et al., [40] studied on Aegiceras corniculatum (L) leaves with different solvents. The ABTS test showed water and methanol extract of leaves of Aegiceras corniculatum L. with EC50 values of 84.38 and 89.33 g/ml and water and methanol extract of bark with EC50 value 87.89 and 102.34 g/ml. While the H_2O_2 method of petroleum ether, water, and methanol extract of leaf obtained the EC50 value of 93.59, 97.07, and 95.05 g/ml. the ethyl acetate extract of the bark showed the value of EC50 93.44 ug/ml. The findings demonstrated that the petroleum ether extract had the lowest antioxidant activity while the methanol and ethyl acetate extracts had the highest antioxidant activity.

Mechanisms of Antioxidant Action

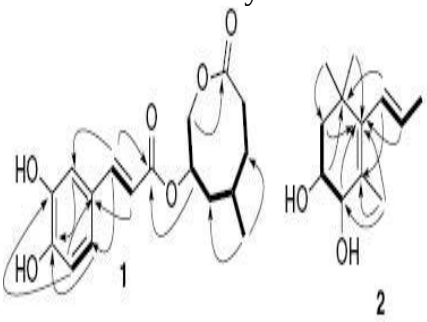
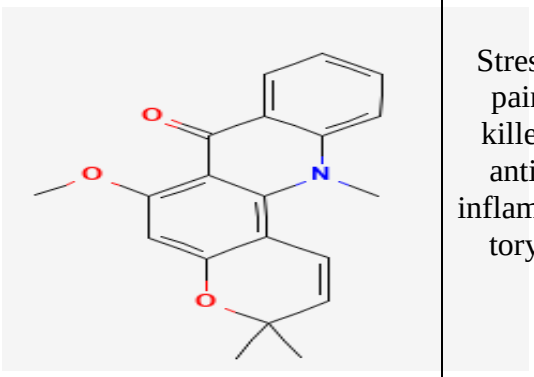
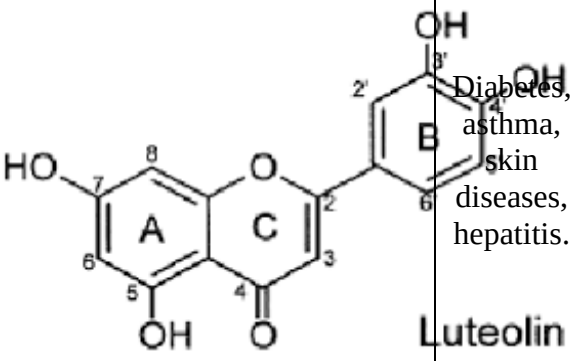
The antioxidant activity of mangrove compounds is mediated through multiple mechanisms, including:

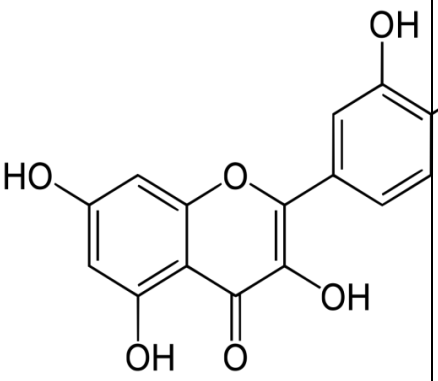
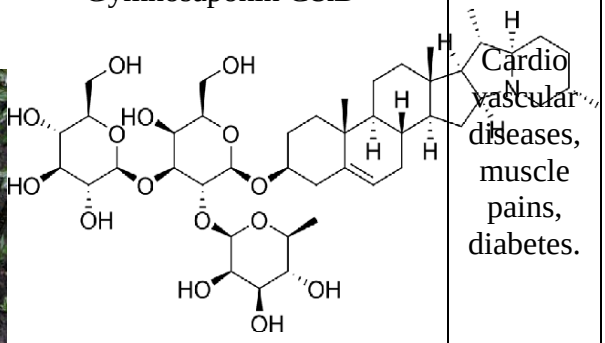
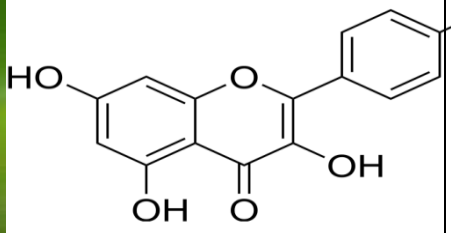
1. **Free Radical Scavenging:** Many mangrove-derived compounds can directly scavenge reactive oxygen species (ROS), thereby preventing oxidative damage.
2. **Metal Ion Chelation:** Certain compounds in mangroves can chelate metal ions, such as iron and copper, which are catalysts in the formation of free radicals.
3. **Upregulation of Endogenous Antioxidants:** Some mangrove extracts have been shown to enhance the activity of endogenous antioxidant enzymes like superoxide dismutase (SOD), catalase, and glutathione peroxidase.

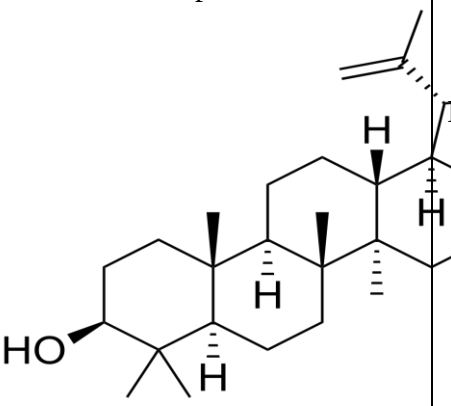
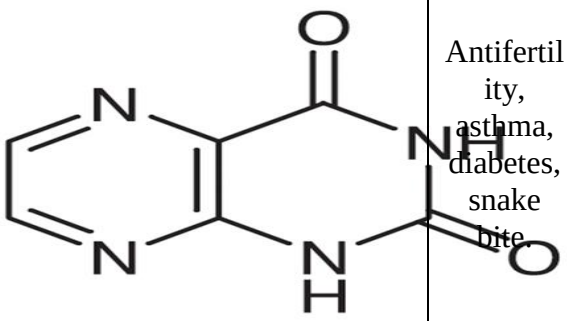
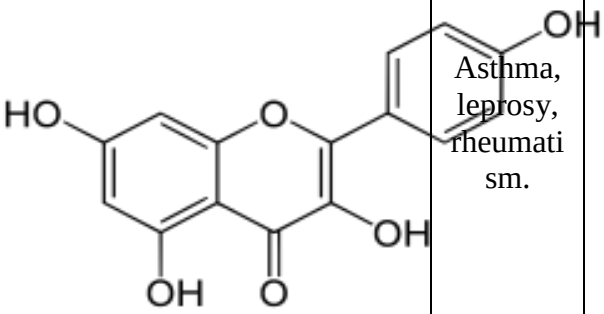
Potential Therapeutic Applications

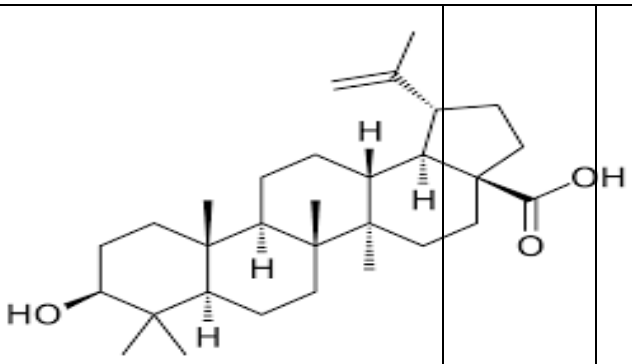
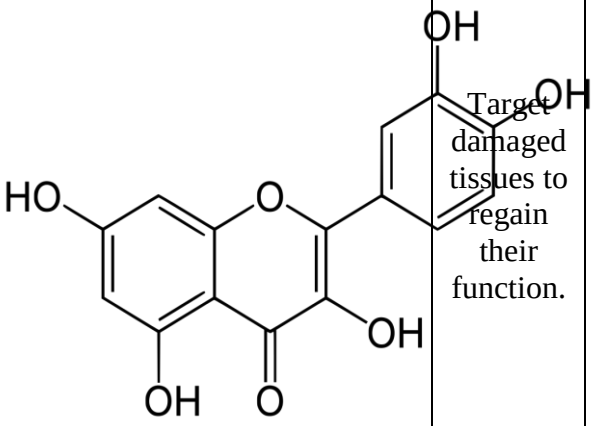
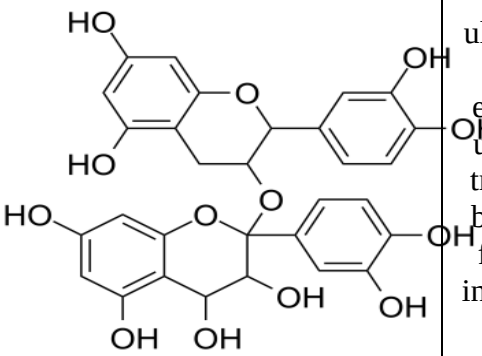
The potent antioxidant properties of mangrove extracts have significant implications for their use in pharmaceuticals, nutraceuticals, and cosmeceuticals.

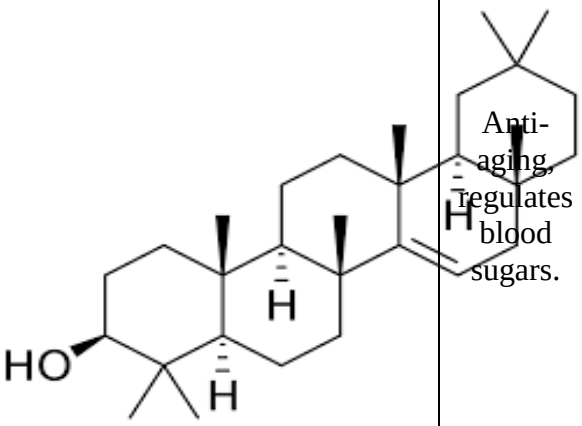
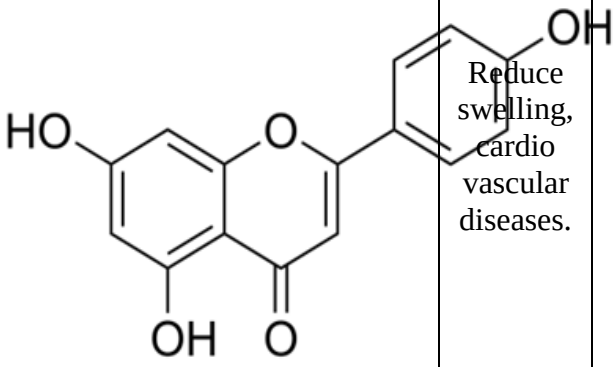
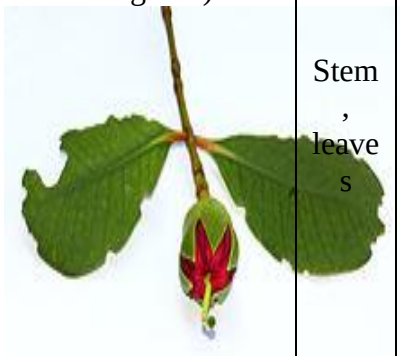
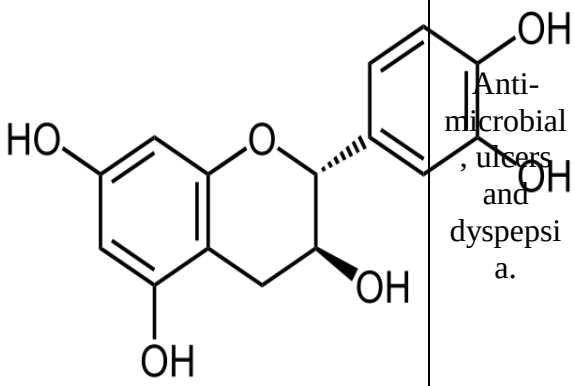
1. **Pharmaceuticals:** Mangrove-derived antioxidants could be developed into therapeutic agents for the prevention and treatment of diseases associated with oxidative stress, such as cancer, cardiovascular diseases, and neurodegenerative disorders.
2. **Nutraceuticals:** The incorporation of mangrove extracts into dietary supplements could provide a natural means of boosting antioxidant defenses in the body.
3. **Cosmeceuticals:** Mangrove antioxidants could be used in skincare products to protect against oxidative damage caused by environmental factors, such as UV radiation and pollution.

S. No	SPECIES	PARTS	BIOACTIVE COMPOUDS	USES	REFERENCE
1.	**Avicennia marina** (Grey Mangrove) 	Stem, Bark	Maricaffeolylide A 	Diabetes, cancer.	(11,36)
2.	**Aegiceras corniculatum** (River Mangrove) 	Bark	Aegicoroside A, Acornin 1 & Acronin 2 	Stress, pain killer, anti-inflammatory.	(40)
3.	**Acanthus ilicifolius** (Holy Mangrove/ Sea Holly) 	Root, leaves, stem, flower	Luteolin 	Diabetes, asthma, skin diseases, hepatitis.	(19)

4.	**Bruguiera gymnorhia** (Large leafed Mangrove) 	Stem and leaves	Quercetin 	Arthritis, diabetes, headaches, cancer therapy.	(32)
5.	**Bruguiera cylindrica** (Small-leafed orange Mangrove) 	Stem and leaves	Gymnosaponin C&D 	Cardio vascular diseases, muscle pains, diabetes.	(39)
6.	**Ceriops tagal** (Spurred Mangrove) 	Stem, roots, leaves	Kaempferol 	Improve insulin sensitivity, cancer treatment, headache.	(20)

7.	**Excoecaria agallocha** (Blind-Your-Eye Mangrove) 	Leaves, stem and root	Lupeol 	Dermatitis, leprosy, toothache.	(4,19)
8.	**Lumnitzera racemosa** (White Mangrove) 	Flower	Lumazine 	Antifertility, asthma, diabetes, snake bite.	(19)
9.	**Nypa fruticans** (Nipa Palm) 	Stem, flower, leaves	Kaempferol 	Asthma, leprosy, rheumatism.	(19)
10.	**Kandelia candel** (Kandelia / Indian Mangrove)	Leaves, bark, roots	Betulinic acid	Inflammatory response	(8,9)

					
11.	**Rhizophora mucronate** (Loop-root Mangrove) 	Bark, leaf, stem	Quercetin 	Target damaged tissues to regain their function.	(2,5)
12.	**Rhizophora mangle** (Red Mangrove) 	Bark	Pronthocyanidins 	Anti ulcerogenic effects, used in treating boils & fungal infections.	(5)

13.	**Rhizophara Stylosa (Stilted Mangrove)** 	Roots	Taraxerol 	Anti-aging, regulates blood sugars.	(10)
14.	**Sonneratia alba** (Mangrove Apple) 	Leaves and stem	Apgenin 	Reduce swelling, cardio vascular diseases.	(35)
15.	**Sonneratia caseolaris** (Caseolaris Mangrove) 	Stem, leaves	Catechins 	Anti-microbial, ulcers and dyspepsia.	(38)

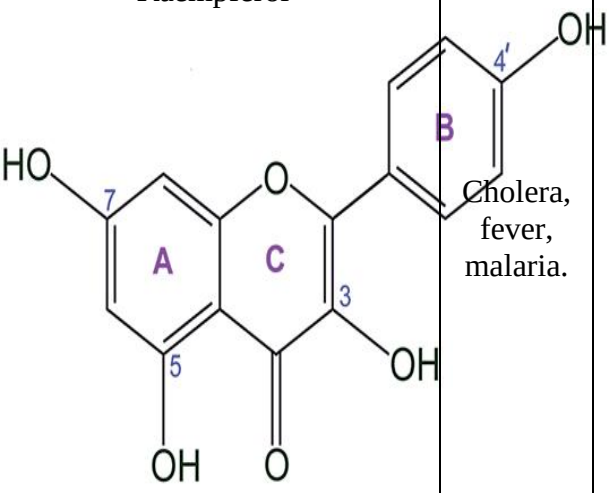
16.	**Xylocarpus granatum** (Cannonball Mangrove) 	Bark, lea	Kaempferol 	Cholera, fever, malaria.	(19,37)

Table:1 List of Bioactive compounds isolated from different Mangroves

4. Conclusion

Mangroves are the most productive ecosystem in the world. The review discusses about the bioactive compounds present in mangroves and their medicinal properties. The alkaloids in mangroves shows biological activities such as anti cancer activity, anti microbial activity and anti oxidant activity for removal of stress and used for treating depression. In addition to these it also possesses neuroprotective & analgesic properties especially for treating chronic pains. The diverse medicinal properties of mangrove terpenoids underscore their importance in drug discovery and development, particularly in addressing resistant infections and chronic diseases. The biological activities of mangrove phenolic compounds highlight their potential in drug discovery and as natural remedies for various health issues. The flavonoids in mangroves underscore their potential in drug discovery and therapeutic applications, offering natural solutions for various health challenges. The tannins present in mangroves exhibits a range of medicinal properties, including wound healing, antimicrobial, antioxidant, anti-inflammatory, and anticancer activities, highlighting their importance in both traditional and modern medicine. The mangrove steroids exhibitmore powerful anti-inflammatory& antimicrobial properties when compared to other compounds. They play crucial role in insulin production shows impact on blood sugars. Saponins have significant hepato protective property, can regulate the blood glucose level maintains cholesterol preventing cardio vascular diseases. Saponins also possess unique wound healing property promoting cell proliferation.

Mangroves, with their rich phytochemical diversity, represent a valuable source of natural antioxidants with potential applications in health and industry. According to this review paper, mangrove plants such as Rhyzophora mucronata, Nypafruticans, Avicennia marina, Sonneratia alba, and Acanthus ilicifolius (L) have strong antioxidant activity as demonstrated by the DPPH assay. A low value of inhibition concentration of 50% (IC50) indicates a higher antioxidant activity. The presence of secondary metabolites such flavonoids, phenolics, saponins, and tannins in the extract is what gives mangrove plants their antioxidant activity. Further research is needed to fully explore the therapeutic potential of mangrove-derived compounds and to develop effective methods for their extraction and utilization. As the global demand for natural antioxidants continues to grow, mangroves offer a promising and

sustainable source for these vital compounds. The below table (2) show the different phytochemical activities by isolating the bioactive compounds.

SNo	Bioactive compounds	Anti-Microbial	Anti-cancer	Anti Inflammatory	Anti-Oxidant	Anti Analgesic
1.	Alkaloids	✓	✓	✓	✓	✓
2.	Terpenoids	✓	✓	✓		
3.	Phenolic compounds	✓	✓	✓	✓	
4.	Steroids	✓	✓	✓		
5.	Saponins	✓	✓	✓	✓	

Table.2 Bioactive compounds and their properties

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