Mangrove Ecosystems: A Promising Source of Novel Antibiotics and Their Ecological and Human Health Significance

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Abstract:

Mangrove forests, resilient ecosystems flourishing along tropical coastlines in response to rising sea levels, derive a diverse array of physical, chemical, and biological attributes from both the ocean and adjacent highland forests characterized by estuarial trees. Serving as ecotones bridging the interface between land and sea, mangrove swamps exhibit horizontal and vertical stratification between forest cover and underlying soil. Phytochemical analysis reveals the presence of terpenoids, tannins, steroids, alkaloids, flavonoids, and saponins as the primary compounds in mangroves. Given their rich chemical composition, mangroves hold immense potential for the development of health-enhancing products and medicinal compounds targeting a wide range of diseases. In recent times, recognition of the ecological significance and human benefits offered by mangroves has grown considerably, particularly in light of the antibiotics and therapeutic substances derived from these ecosystems. Nevertheless, certain aspects of the current system remain unclear, such as the distribution of antagonistic actinomycetes. Moreover, research efforts focused on the ecology, phytogeography, biology, and other facets of mangrove systems are limited, especially in Asian countries. This review aims to underscore the pivotal role of mangrove ecosystems in providing essential benefits to humanity.

Keywords: Mangroves, Actinomycetes, Alkaloids, Saponins, Antagonistic.

1. Introduction

Mangroves are among the most efficient marine ecosystems on Earth, imparting a unique habitat with the possibility to inhabit lots of species and key resources and amenities for human beings. Mangrove habitats are regressing at an alarming rate, because of direct anthropogenic influences and worldwide change [1]. In this article we will determine the results of mangrove habitat degradation on benthic biodiversity and environment functioning. We investigated meiofauna biodiversity (*as proxy of benthic biodiversity*), benthic biomass and prokaryotic heterotrophic production (*as proxies of environment functioning*) and trophic state in a disturbed and an undisturbed mangrove forest [2]. We verified that disturbed mangrove location confirmed a loss of 20% of benthic biodiversity with the nearby extinction of 4 Phyla (*Cladocera, Kynorincha, Priapulida, Tanaidacea*), a lack of 80% of microbial-mediated decomposition rates, of the benthic biomass and of the trophic resources [3]. The effects of this take a look at improve the need to keep mangrove forests and to repair the ones degraded to assure the availability of products and offerings had to assist the biodiversity and functioning of huge quantities of tropical ecosystems [4, 5].

1.1. Mangroves

Mangroves are hardy shrubs and trees that grow in coastal saline or brackish water, mainly in the tropics and subtropics. They have special adaptations to cope with saltwater immersion and low-oxygen conditions of waterlogged mud. They are among the most productive and diverse ecosystems in the world, providing many ecological and economic benefits [4]. Mangrove swamps occupy about 181,000 k.m or approximately 75th of the world's tropical and subtropical coastlines. Mangroves are typically tropical trees that develop among the extreme spring tide marks in solid shores and close to mean ocean levels. mangrove needs five criteria to be thought of a “true or strict mangrove” mostly, complete fidelity to the mangrove environment; plays a major role at intervals the structure of the community and has the capability to create pure stands; morphological specialization for adaptation to the habitat; physiological specialty for adaptation to their habitat; and classification isolation from terrestrial relatives [6,7]. Mangroves square measure thus singular surroundings with productive ecosystems (global litter fall of a hundred TgC year-1) [8]. The compulsory physical options of the mangrove trees that aid their survival at intervals the boundary zone among ocean and land square measure diversifications for mechanical fixation in loose soil, specialized dissemination mechanisms, respiratory roots and air conversation devices, and specialized mechanisms for handling excess salt concentration. In terms of distribution, Indonesia is the primary source of mangroves, occupying the foremost significant area globally [8,9,10].

These plants type a rare and distinctive ecosystem however are vulnerable since they're destroyed 5 times quicker than tropical forests. As an example, North and Central America are recognized because the most threatened mangrove regions thanks to coastal development, hurricanes, and aquaculture. Aqua culturing of shrimps, mud crabs, or oysters may be a critical staple job for several people in Southeast Asia. However, aquaculture is recognized as a number one threat to mangroves. It’s considered that 90% of the mangrove forests are found in developing countries [11].

The aim of this article is to explore the potential of mangrove ecosystems as a source of antibiotics and investigate their ecological significance and advantages to the human race, particularly in the development of novel antibiotics for preventing and treating various diseases. The objectives of this review article are to comprehensively examine the existing body of literature on antibiotics obtained from mangroves. Firstly, we aim to compile and summarize information on mangrove species known to produce antibiotics, their geographic distribution, and the specific antibiotic properties they possess. Secondly, we will analyze the phytochemical diversity of mangroves, with a focus on terpenoids, tannins, steroids, alkaloids, flavonoids, and saponins, which are the key compounds associated with antibiotic activity. Additionally, we intend to review and synthesize findings from in vitro and in vivo studies assessing the antibacterial activity of mangrove-derived compounds against various bacterial pathogens. Furthermore, we will investigate the mode of action of these antibiotics to understand their potential for combating antibiotic-resistant bacteria. Moreover, this review aims to discuss the ecological significance of antibiotic-producing organisms in mangrove ecosystems and their role in maintaining ecosystem health and biodiversity. Furthermore, we will highlight potential pharmaceutical applications of mangrove-derived antibiotics, evaluating their efficacy, safety, and scope in treating bacterial infections. Ultimately, we will identify knowledge gaps in the field and suggest areas for future research, while also emphasizing the importance of conserving mangrove ecosystems for their unique biodiversity and pharmaceutical potential [11].

1.2. The Origin of the species

According to scientific theory, the earliest mangrove species originated inside the Indo-Malayan region. This may account for the fact that there are way more mangrove species present near this region than in any other place. Due to their unique floating propagules and seeds, these early mangrove species spread westward, borne by ocean currents, to India and East Africa, and eastward to the Americas, coming in Central and South America throughout the higher Cretaceous and lower Miocene between sixty-six and twenty-three million years ago. During that time, mangroves unfold throughout the Caribbean Sea across an open sea lane that once existed wherever Panama lies today. Later, sea currents might have carried mangrove seeds to the western coast of Africa and as way south as New Zealand. This might make a case for why the mangroves of geographic region and so earth contain fewer, however similar colonizing species, whereas those of Asia, India, and geographical area contain the way fuller verity of mangrove species [12, 13].

1.3. Antibacterial action

The antibacterial potential of leaves and bark of mangrove plants, Blackwood (*Avicennia germinans* (L.), *Avicennia officinalis*), *Exoecaria agallocha*, *Lumnitzera racemosa*, and *Rhizophora apiculata* become evaluated in opposition to antibiotic-resistant unhealthful microorganism, *Staphylococcus aureus* and Proteus species. Soxhlet extracts of plant with oil, ether, ethyl radical acetate, and water were prepared and evaluated the antibacterial activity the usage of agar diffusion methodology. Most of the plant extracts confirmed promising antibacterial activity in opposition to every microorganism species [7,8]. However, higher bactericide activity was placed for *Staphylococcus aureus* than *Proteus* species. The very best antibacterial activity was shown by organic compound of mature leaf extracts of *E. agallocha* for *Staphylococcus aureus*. All organic compound extracts showed higher inhibition against *S. aureus* while some extracts of chloroform, organic compound and plant product gave inhibition against Proteus sp. None of the crude oil ether and liquid extracts confirmed inhibition in opposition to Proteus sp. All sparkling plant substances did in addition showed further antibacterial activity of clean to every microorganism strain than did dried plant extracts. Bactericide activity of unpolluted and dried plant substances reduced for every microorganism strain with time when extraction [7]. Since *Laguncularia racemosa* and *Avicennia dockage* gave the foremost effective inhibition for microorganism species, there need has been used for additional investigations. Also, charcoal-treated plant extracts of *Laguncularia racemosa* and *Avicennia marina* were able to inhibit bacterial strains quite those of untreated plant extracts. Phytochemical transmission of mature leaf, bark of *L. racemosa* and leaf extracts of *A. dockage* would be administered and discovered that leaf and bark contained alkaloids, steroids, triterpenoids, and flavonoids. None of the higher than extracts recommend the presence of saponins and internal organ glycosides. Separated bands of extracts via method of suggests that of tending analysis confirmed bacteria activity towards *S. aureus* [14].

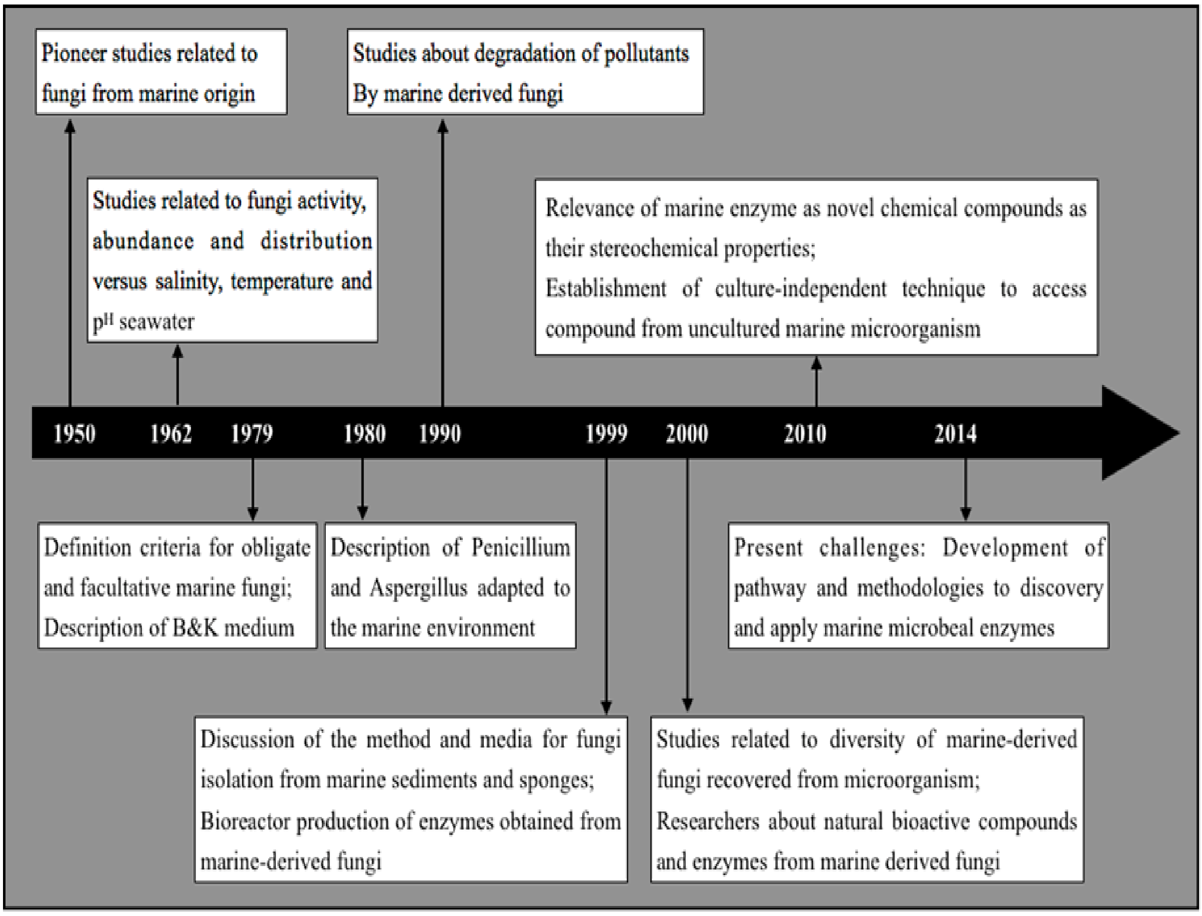

Fig 1: Development of Antifungal bioactive compounds

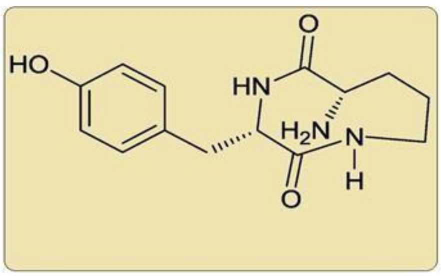

Fig 2: Mangrove Actinomycetes

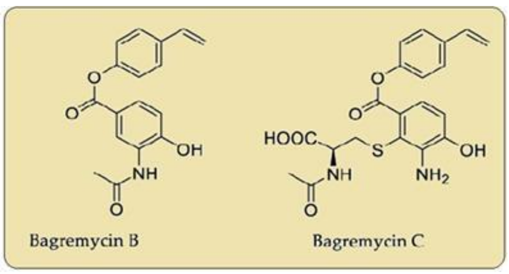

Fig 3: Mangrove Antibiotics Bagremycin B/C

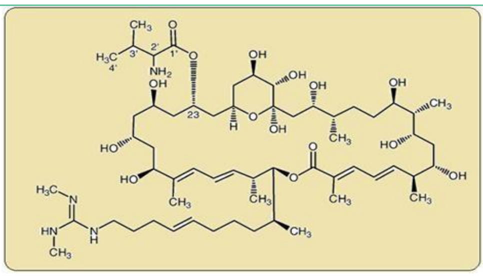

Fig 4: Mangrove Antibiotics Streptomycin

2. History

The first article was published in 1955, each classified into 11 major research topics and including studies from each of the regional seas (Red Sea, Arabian Sea, Sea of Oman, and therefore the Persian/Arabian Gulf). The effects show that there was an exponential boom in studies on local mangroves in the latest decades (in particular around human influences and ecology). The study further reveals knowledge gaps in crucial research subjects and geographical areas that would be exploited to deliver insights into broader biogeographic issues. These effects offer a comprehensive assessment of the developing body of data on regional mangroves and supply direction for future studies, which will guide conservation, management, and knowledge domain of those important ecosystem engineers [15,16].

The earliest known mangrove plant groups arose sometime during the Late Cretaceous and Paleocene epochs, and their subsequent widespread distribution can be attributed in part to the shifting of tectonic plates. Mangrove palm fossils date to roughly 75 million years ago. Ocean currents are credited by botanists with spreading mangroves from Southeast Asia to India, Africa, Australia, and the Americas [16].

Antibiotics are chemicals that kill germs or stop them from multiplying. The advent and spread of antibiotic-resistant bacteria (ARB) and antibiotic-resistant genes (ARG) make their widespread use in human and veterinary treatment a double-edged sword. Antibiotic-resistant bacteria and genes are a growing problem because they complicate the treatment of infectious diseases. Antibiotics and ARB/ARG come into contact with mangroves via a wide variety of human and nonhuman activities, including wastewater treatment, aquaculture, tourism, and the microorganisms native to mangroves themselves [17,18]. The danger that these pollutants pose to mangrove ecosystems, however, is little known. Depending on the surrounding circumstances and microbial interactions, mangroves have been suggested to either store or filter ARB/ARG. Antibiotics like sulfamerazine and sulfamethazine and ofloxacin and norfloxacin and ciprofloxacin and oxytetracycline and tetracycline have been discovered to be less concentrated in sediments with mangrove vegetation than on bare mudflats [19]. If true, this would suggest that mangroves may help clean the environment of antibiotics by breaking them down or removing them. In addition, it has been proven that some microbes living in mangroves create new antibiotics with medical uses. As an example, a Streptomyces strain was isolated from Chinese mangrove silt that produced a novel class of indolocarbazoles with anticancer potential. Mangrove soil in Vietnam was the source of a novel cyclic peptide with antibacterial action against methicillin-resistant Staphylococcus aureus (MRSA). Therefore, mangroves are crucial for bioprospecting of novel antibiotics and bioremediation of antibiotic contamination, in addition to their importance in conserving biodiversity and providing ecosystem services [18].

3. Current knowledge

Over the final decade, microplastics (MPs, plastic particles <five mm) as rising contaminants have acquired an outstanding deal of global attention, now no longer handiest due to their non-stop accumulation in each marine and terrestrial environment, however additionally because of their critical threats posed to the environment. Voluminous studies concerning sources, distribution characterization, and fate of MPs within the completely different environmental compartments (e.g., marine, freshwater, wastewater, and soil) are reportable since 2004, whereas MPs pollution in distinctive marine ecosystems (e.g., coastal angiosperms' tree

habitat) receives very little scientific attention. Mangrove ecosystem, a crucial buffer between the land and therefore the sea, has been known as a possible sink of MPs caused by each marine and land-based activities [20,21].

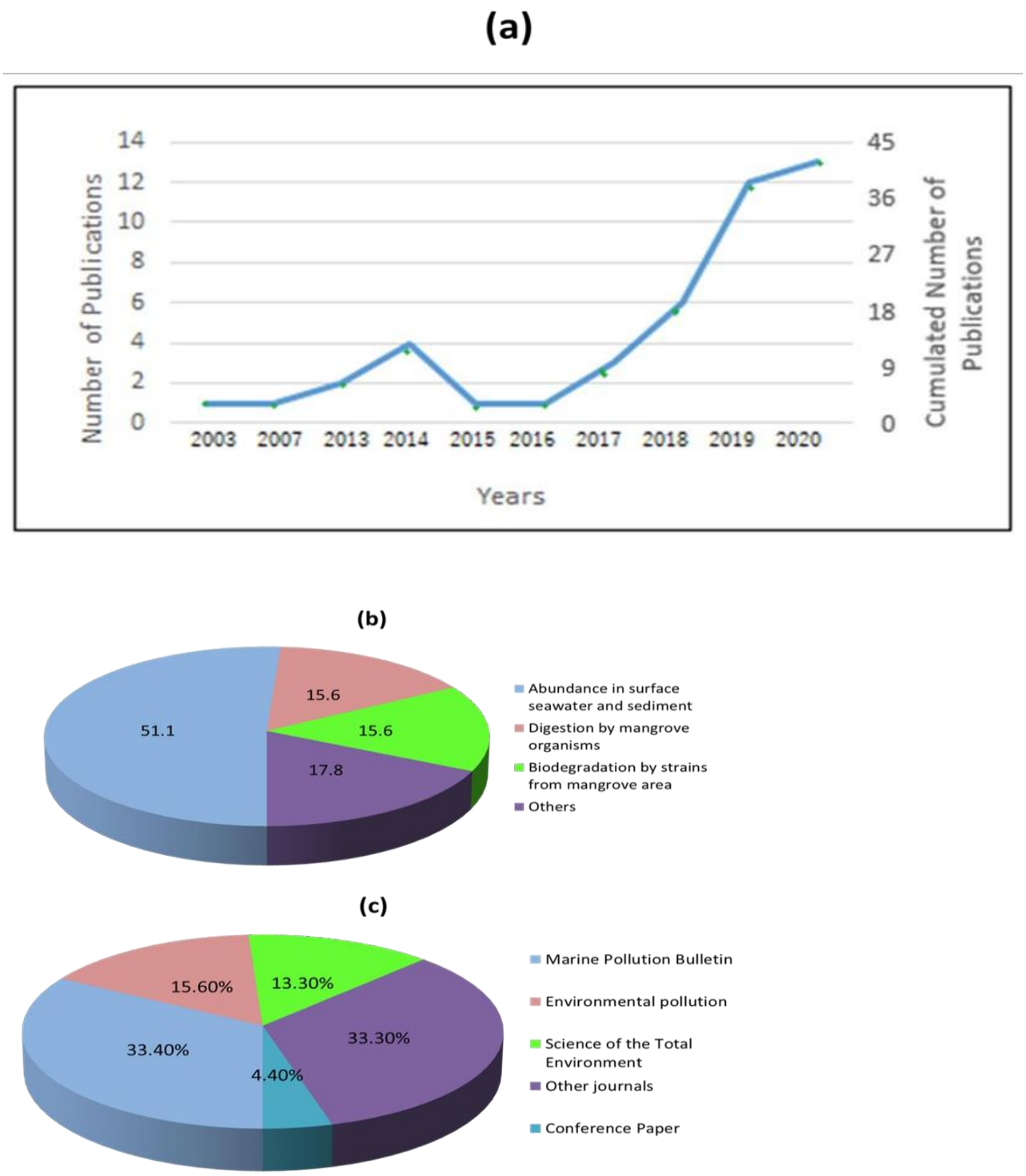

Fig 5: (a) Evolution of Mangrove obtained antibiotics; (b) Fate of MPs of micro plastics within the marine ecosystems; (c) A representative of micro plastic studies as represented across diverse journals and scientific publications.

4. Enzymes & Metabolites

Mangrove-associated bacterium are of commercial interest because of their numerous and versatile enzyme properties. Study shows the culturable bacteria from a large range of environment in an exceedingly *Bruguiera cylindrica* mangrove system in North Sumatra. Screening of extracellular hydrolytic enzymes showed multiple potential traits in amylase, cellulase, chitinase, phosphatase, protease, and enzyme production by microorganism isolates. Molecular identification supported 16S rDNA region of a possible strain, vibrion alginolyticus Jme3−20 is then reportable as a freshly chemical action agent. The strain additionally showed a stable growth below salinity (NaCl) stress with substantial phosphate solubilization activities. Protease activity was increased by optimizing the 0.5 percent (w/v) sucrose and soy organic compound within the fermentation medium [22]. SDS-PAGE and zymogram analysis showed the presence of a 35-kDa MW protease. Hence, our study discovered very important insights into the organism diversity and activity in mangrove ecosystems, evidencing the importance of microbic exploration throughout this ecosystem [23].

Fig 6: Mangrove Forest

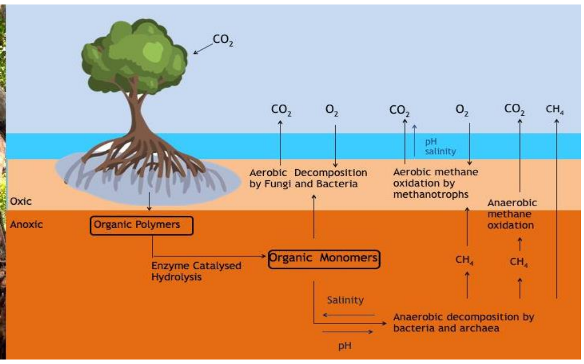

Fig 7: Mangrove Forest Ecosystem

Mangroves are coast extreme environments with microorganism communities. Actinobacteria are accepted for manufacturing antibiotics. The search for synthesis potential of Actinobacteria from mangrove environments might offer additional potentialities for helpful secondary substances. A study says whole genome sequencing and MS/MS analysis were accustomed to explore the secondary metabolite production potential of an actinobacterial strain of actinomycete *olivaceus* sp., isolated from a mangrove in Macau, China. The results showed that a complete of one hundred and five sequence clusters were found within the genome of *S. olivaceus* sp., and fifty-three known secondary metabolites, together with bioactive compounds, peptides, and alternative products, were expected by ordination mining. There have been twenty-eight secondary substances classified as antibiotics that weren't antecedently well-known from *S. olivaceus* [24]. ISP medium a pair of was then accustomed ferment the *S. olivaceus* sp. to see which expected secondary metabolite might be really created. The analysis disclosed that ectoine, melanin, and therefore the antibiotic of validamycin A could be determined within the fermentation broth. This was the first observation that these compounds are often made by a strain of *S. olivaceus*. Therefore, it can be complete that Actinobacteria isolated from the mangrove atmosphere have unknown potential to provide bioactive secondary metabolites [25].

Human pathogens such *Staphylococcus aureus*, S*treptococcus* sp., *Salmonella typhosa*, *Proteus vulgaris*, and *Proteus* genus *Mirabilis* were tested for susceptibility to mangrove leaf extract from Chorao Island, province. *S. alba* and *E. agallocha* binary compound extract was effective against both *P. vulgaris* and *P. mirabilis*. Saponins, glycosides, tannins, flavonoids, phenol, and oils were all discovered through a phytochemical analysis of mangrove leaves. Mangroves may be a far better source for the discovery of new antibiotics, but this claim needs to be confirmed by more experiments using completely different solvents for extraction. Infectious diseases kill 14 million people per year, making microbial infections a major global concern. Antibiotics and other chemicals are currently the only viable solution to the problem. However, researchers have been screening plants for their antibacterial activity due to the rising failure of therapy and antibiotic resistance displayed by bacterial infections. Therefore, it is necessary to seek out new antimicrobials for all emerging and re-emerging microbial infections. Drug discovery based on plant materials continues to rise in popularity, as does the practice of discovering the structures of active chemicals from extracts. There are untapped potential advantages of natural products that could lead to the development of novel therapeutics. Finding a reliable supply is the focus of drug research. Mangroves can be found in higher abundance if unspoiled habitat is explored [26].

5. Mangroves throughout the world

Mangroves are well opened up round the world in 123 tropical and semitropic countries consisting of seventy-four true angiospermous tree species, as well as trees, shrubs, palms, and ferns. In Africa, mangrove populations are well detached throughout. Over seventy true mangrove species are recorded from all round the world, and this selection may not be specific as a result of many of its genus are wiped out by the villages shutting the area. The distribution of the species is kind of varied, from the famous species of mangrove, eight out of seventeen of those mangroves are distributed in 26 African countries whereas nineteen out of them are in primarily in West a part of Africa and also the alternative 9 species are expanse in seven countries around East African Countries. As regards the distribution parts, the mangroves population also extends its spreading [27].

South America occupies quite a sizable amount of mangroves environment with 50% of its population placed in Brazil. The distribution of mangroves in Asia, compared to different continents, is considered the foremost various and well-distributed. A region known as the Sundarbans is the largest mangrove forest within the world and is widely acclaimed for its biodiversity. The Asian continent is very ideal for the expansion of mangroves because it has long coastlines, a large vary of climates from arid, like in the Arabian Peninsula, to subtropical, like in China and Japan, furthermore as wet tropical, like in the Southeast Asia region [27, 28].

6. Mangrove extraction and isolation

The mangrove ecosystem comprises a variety of species from where medicinally and potentially active compounds can be extracted, isolated, identified and documented in a precise manner to establish scientific methods. Here, the methods of extraction from plants and microbes from sediments have been discussed. The following is a generalized protocol for extracting bioactive chemicals from mangrove plants and trees: [29,30]

- **Plant Collection:** Obtain the mangrove plant or tree that has bioactive chemicals of interest. Be sure the specimen is healthy and typical of the species of interest.
- **Drying and Grinding:** It is recommended that the plant material be dried after collection. The plant matter should be powdered after drying because of the enhanced surface area, extraction is facilitated.
- **Solvent Extraction:** Extract the bioactive components from the powdered plant material using a suitable solvent (such as ethanol, methanol, or dichloromethane). The properties of the chemicals you're trying to extract will dictate which solvent is best. Maceration, Soxhlet extraction, or sonication can all be used to accomplish the extraction.
- **Filtration:** Extract the solvent and filter it afterward. Isolate targeted bioactive components by subjecting the fractions to additional purification steps, such as HPLC.Extract the bioactive components from a crude extract after extract to remove solid particles and contaminants.
- **Purification:** Isolate targeted bioactive components by subjecting the fractions to additional purification steps, such as HPLC.

- **Identification and Characterization:** For the purpose of identifying and characterizing the separated bioactive chemicals, spectroscopic techniques such as nuclear magnetic resonance (NMR) and mass spectrometry (MS) should be employed.
- **Bioactivity Testing and further studies:** The potential medicinal or functional qualities of the isolated compounds can be evaluated by subjecting them to a multitude of biological experiments.
- **Documentation:** To guarantee the reproducibility and traceability of the isolating procedure, record all stages and outcomes precisely in a research log or laboratory notebook.

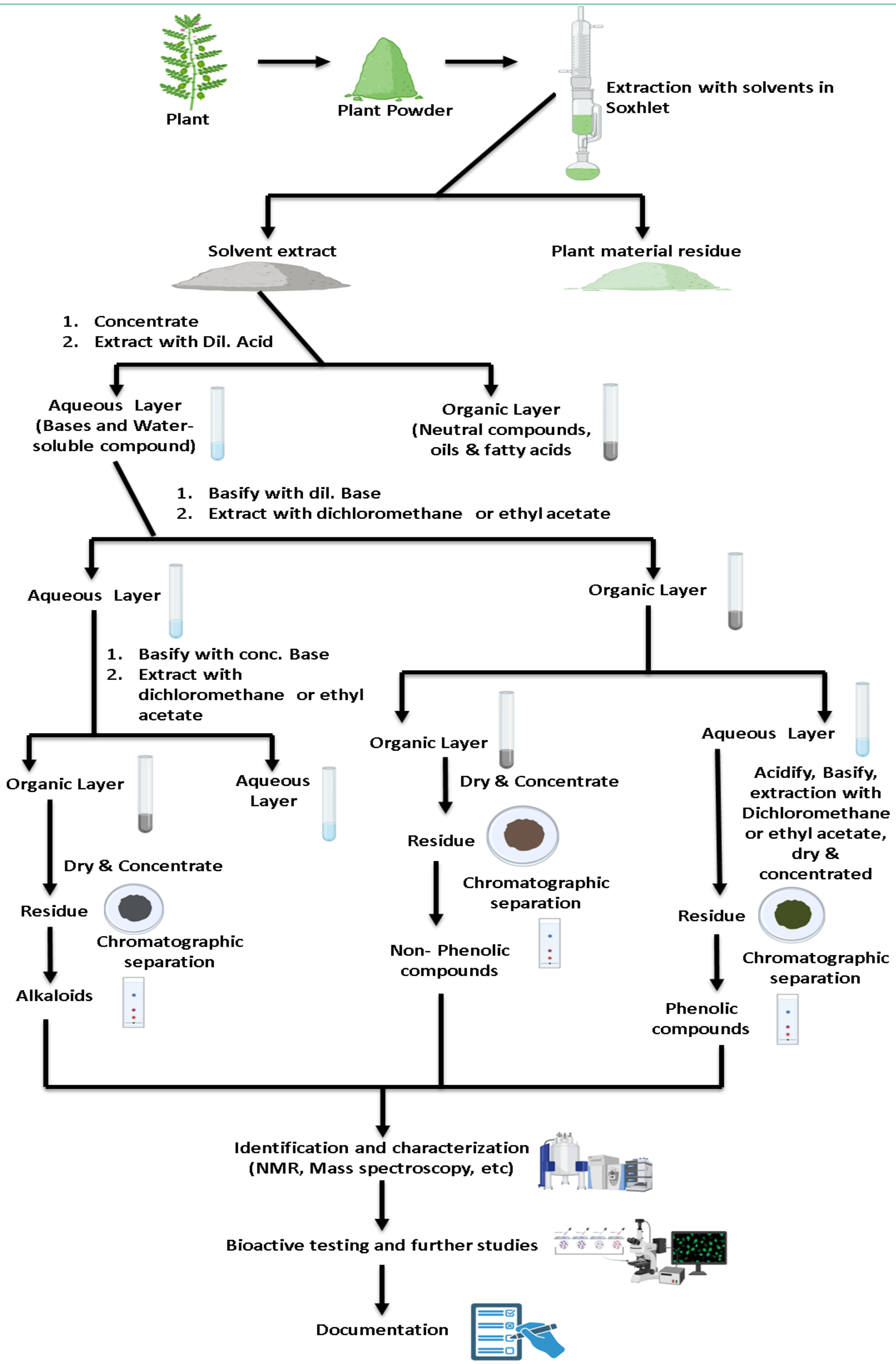

Fig 8: Extraction of plant material

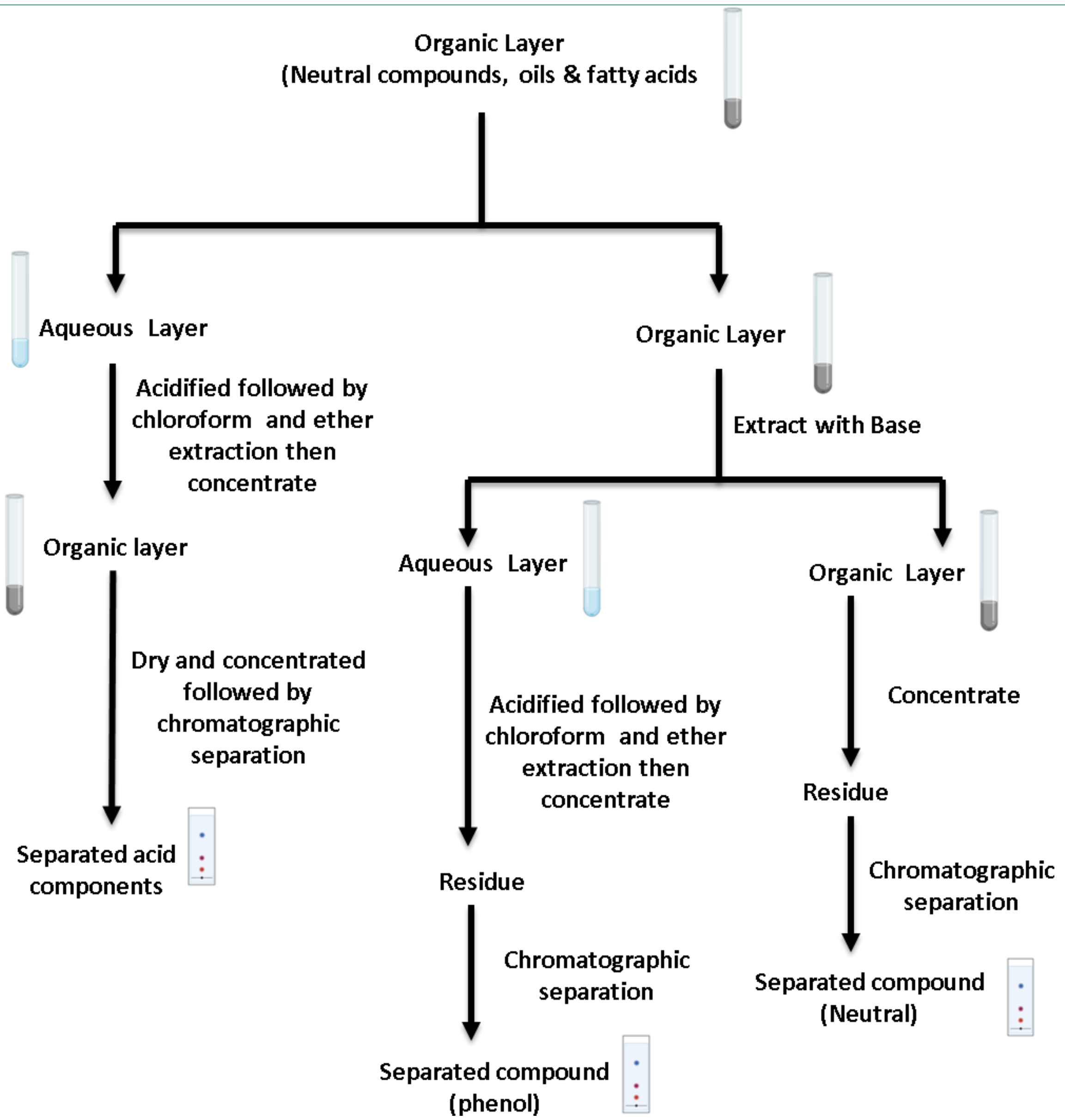

Fig 9: Extraction of organic material

There is a wide range of biological and industrial uses for the natural products found in mangroves. One article claims that microbes in mangrove ecosystems contain enzymes, proteins, antibiotics, and salt-tolerant genes that are very important in biotechnology [30].

Methods for isolating and identifying bioactive chemicals from mangrove microorganisms include the following:

- Collect mangrove sediments or plant tissues from different locations and depths and store them in sterile containers at low temperature.
- Isolate microorganisms from the samples by serial dilution and plating on different media, such as marine agar, nutrient agar, or selective media.
- Screen the microbial isolates for their bioactivity against different targets, such as cancer cells, microbes, enzymes, or receptors. It can be achieved by methods such as disk diffusion assay, microdilution assay, cytotoxicity assay, or enzyme inhibition assay.
- Select the most promising microbial strains and grow them in large-scale liquid cultures under optimal conditions.
- Extract the organic biomolecules from the microbial cells using liquid-liquid extraction with organic solvents, such as ethyl acetate, chloroform, or methanol.
- Purify the crude extracts by chromatographic techniques, such as high-performance liquid chromatography (HPLC), thin-layer chromatography (TLC), or column chromatography.
- Characterize the structure and properties of the purified compounds by spectroscopic methods, such as mass spectrometry (MS), nuclear magnetic resonance (NMR), infrared spectroscopy (IR), or ultraviolet-visible spectroscopy (UV-Vis).

It’s essential to note that the isolation procedure can vary depending on the specific bioactive compounds targeted and the resources available in the laboratory. Additionally, researchers should follow ethical guidelines and obtain necessary permits for collecting mangrove plant samples, especially considering the conservation status of certain mangrove species [29,31,32].

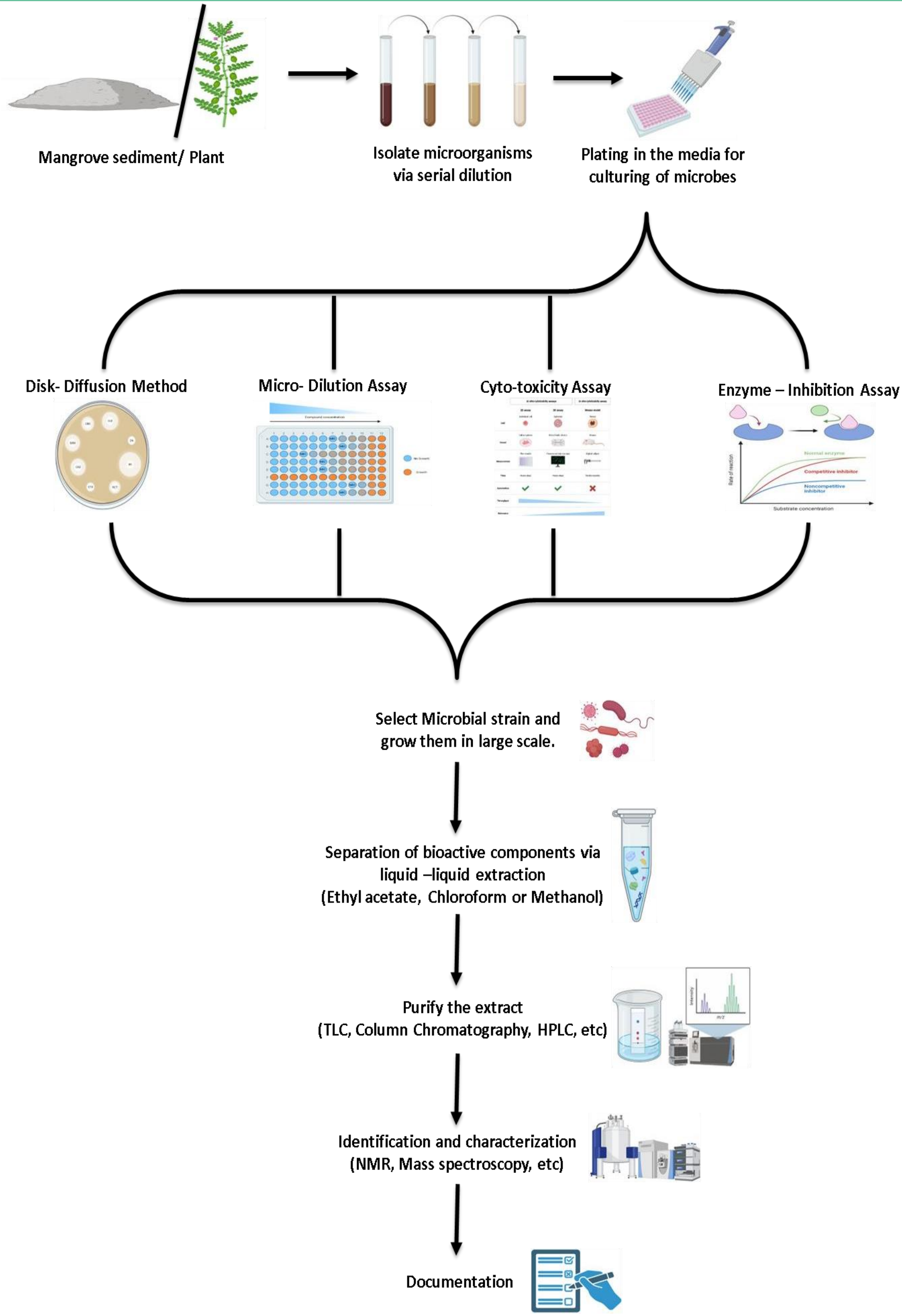

Fig 10: Extraction from Microorganism from Mangroves sediment/ plants.

7. Phytochemicals and Drug delivery

Phytochemicals are often categorized as carotenoids, phenolics, alkaloids, flavonoids, and compounds containing elements and compounds containing organosulfur. Phenolics and carotenoids are the foremost researched of phytochemicals. Since an extended time ago, healthful plants of various origins have been wanted to treat wounds, burns, and even severe health problems. Speedy progress has been established in phytochemical analysis and flavored goods. Nonetheless, the chemical compounds of most flowering tree plants don't seem to be extensively studied yet. Totally different colours can be used to known and analyze different compounds of phytochemical contents [27,33,34].

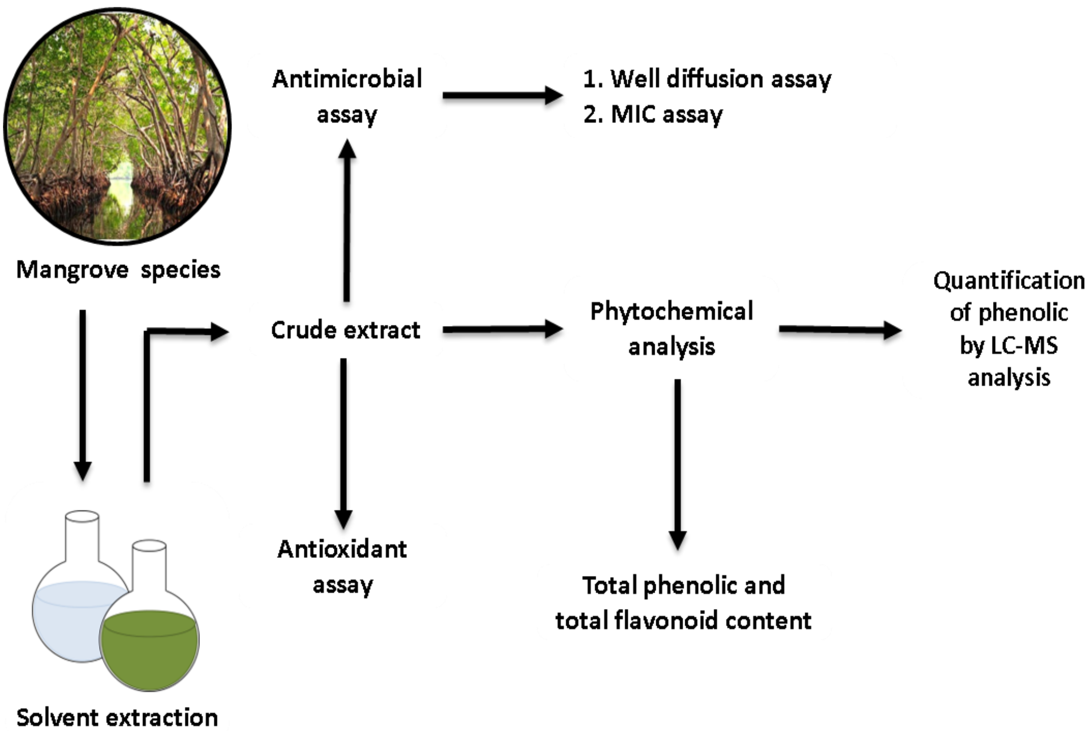

Fig 11: A diagram illustrating the characterization and utilization of various phytochemicals extracted from mangroves

8. Uses of mangroves

Mangroves are a type of plant that grows in coastal areas and can withstand high levels of salt. The bioactive substances produced by mangrove trees have numerous therapeutic properties, including those of antioxidant, antibacterial, anti-inflammatory, anticancer, and anti-diabetic [35,36,32,37,34,33,26,38]. A wide variety of chemicals, including steroids, triterpenes, saponins, flavonoids, alkaloids, and tannins, have been identified from mangroves. Snake bites, diabetes, malaria, ulcers, psoriasis, and eczema are just some of the many conditions that mangrove extracts can help alleviate. The locals can get food, fuel, lumber, tannins, and colours from mangroves. Mangroves are highly beneficial plants that contribute to people's health and happiness in numerous ways [30,39].

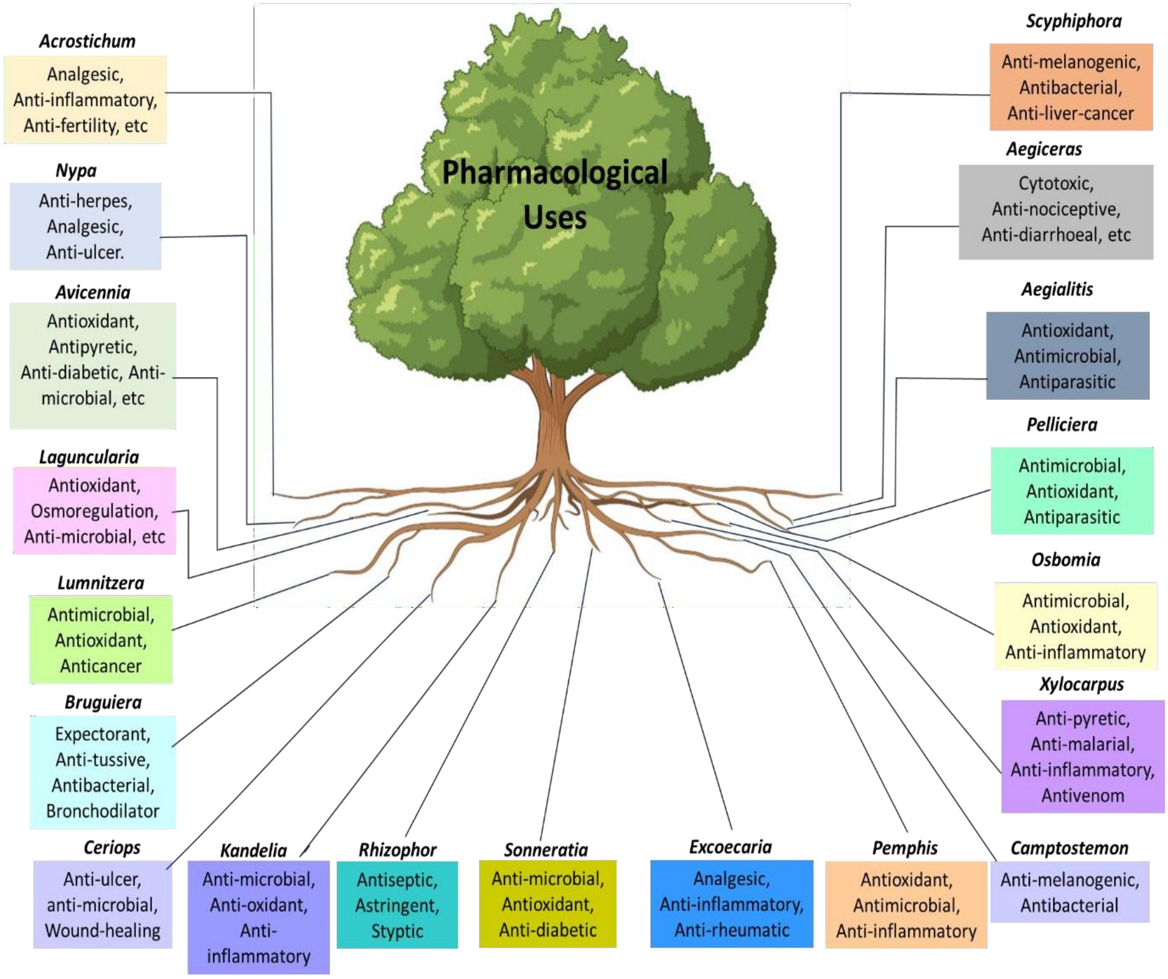

Fig 12: A schematic illustration depicting the various pharmacological effects of antibiotics derived from mangroves

Conclusion

In recent years, analysis on medicinal plants has attracted plenty of attention thanks to their importance and risk for treatment of human diseases. Mangroves are distinctive cluster of vascular plants that occur in saline coastal habitats and are far-famed to tolerate extreme environmental conditions. Some Rhizophora mangle plants are used for a large vary of conditions, as well as bacterial, fungal, and infectious agent diseases [40].

The use of plants and plant merchandise as medicines might be derived as far back as the start of human civilization. Mangrove plants are normally applied in traditional knowledge medicines and extracts from mangrove species have proved restrictive activity against human, animal, and plant pathogens. The current review deals with the medical specialty activity of mangrove medicinal plants. Many species of mangrove prove bioactive compounds that may management microorganism growth. Also, preliminary studies have incontestably that the mangrove plant extracts have antibacterial activity against morbific bacterial strains. Mangrove extracts may be the potential sources of two-winged insect’s larvicides, antifungal, antiviral, anti-cancer, and anti-diabetic compounds.

The rise of antibiotic-resistant microorganisms is one of the severe issues in the healthcare systems of the world, and infectious diseases are the second most serious reason for death worldwide. Therefore, new medicine has to be compelled to be found so as to combat such diseases and it's essential to search out new compounds that have antimicrobial properties. Medicinal-plant extracts, far-famed to supply bound bioactive molecules that react with different organisms within the environment, are known to be less toxic to humans and are environmentally friendly thanks to the less waste material discharged throughout production.

The antimicrobial properties of healthful plants are being reported more and more worldwide. Mangroves are biochemically unique and turn out a good array of novel natural products and are thought to be an expensive supply of steroids, triterpenes, saponins, flavonoids, alkaloids, and tannins. Extracts from the leaves, stems, barks, and roots of angiospermous tree species have shown positive results for antioxidant activity tests. Effects of mangrove extracts on some microorganisms, as well as enteric bacteria sp., cocci sp., and genus Pseudomonas sp. are reportable in some studies within the space of pharmacology.

There are several uses of mangroves. Humans are at risk of many diseases and viruses. To seek a replacement various supply of medicine have become prominent. Mangroves have verified to own the potential to be used as anticancer, antitumor, anti-inflammatory, antiviral, antifungal, antimicrobial, and medicine in medicine. With these advantages that the mangrove plants will give to the medical field, there's little question that they're a necessary member of healthful plants and will be treated that way. The elemental ecological roles mangroves species play got to be understood to safeguard our surroundings as these species and their habitats are vulnerable thanks to speedy coastal development, in depth aquaculture, temperature change scenarios, and overharvesting [41].

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