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Mangrove Fungi for the Future

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ABSTRACT

Mangicolous fungi are biologically diverse and ecological important to determine the productivity of mangrove ecosystems. The mangrove fungi are largely untapped for bioprospecting potential. Further studies are required for enzymes and novel chemical entities especially glycolipids from the mangrove fungi.

Keywords: Mangroves, Mangicolous fungi, Fungal diversity, Fungal prospecting

INTRODUCTION

Mangroves are one among the most productive ecosystems on the earth, and their productivity is dependent upon microbes, especially fungi. The mangroves are a microbial "paradise", providing an ideal ecological niche for fungi, and they are inhabited by a large number of fungal communities, known as "mangrove fungi" or "manglicolous fungi". They include mostly marine fungi and a small group of terrestrial fungi, and can be categorized into saprophytic, parasitic, and symbiotic fungi. The fungi play a vital role in litter decomposition, and releasing of nutrients, thereby contributing to the fertility of mangrove environment. The decomposing organic matter ("detritus") along with fungal biomass provides protein-rich food to fishes of the mangrove ecosystems (Kathiresan, 2021). Understanding the mangrove fungi is crucial for bioprospecting and hence, this article reviewed the mangrove fungi, their ecological role, and potential bioproducts for their utility in the future.

DIVERSITY OF MANGROVE FUNGI

Mangrove fungi are biologically diverse due to the habitat diversity such as forests, litter-forest floor, mudflats, faunal assemblages, water bodies, and associated seagrass beds and coral reefs. The mangrove fungal diversity is also due to the availability of different substrates such as submerged roots, trunks, and twigs as well as algae and sessile animals, for fungal colonization. Being located between land and sea, the mangroves support genetically diverse groups of aquatic and terrestrial fungal species that can tolerate varied ranges of environmental conditions (Kathiresan and Qasim, 2005).

Mangrove fungi have been considerably studied, and the highest number of them is recorded in Asia, which may be due to high diversity of mangrove species and extensive surveys undertaken (Sridhar *et al.*, 2012). Over 600 fungi have been listed from different mangroves forests of the world, which include 278 Ascomycetes, 277 Deuteromycetes, 30 Basidiomycetes, and 15 Oomycetes (Schmit and Shearer, 2003).

Only a few fungi are known to be mangrove specific. For example, *Avicennia germinans* specifically acts as a host for the fungal species *viz.*, *Rhabdosphora avicenniae* and *Mycosphaerella pneumatophorae*, whereas *Rhizophora mangle* forms another host for *Didymosphaeria rhizophora* and *Leptosphaeria australensis* (Kohlmeyer and Kohlmeyer, l979).

In Indian mangroves, a total of 103 fungal species under 67 genera has been recorded as the second largest floral diversity next to marine algae. There are 80 fungal species in the west coast, 59 species in Andaman and Nicobar Islands, and 57 species in the east coast of Indian mangroves (Kathiresan, 2000; 2018). The higher record of mangrove fungi is due to extensive surveys, made from the west coast of India (Patil and Borse, 1983; Raghukumar, 1973). *Aspergillus* and *Penicillium* are predominant fungal species. Eleven new species and 13 new genera of filamentous fungi have been described from Indian mangroves. To cite a few, *Passeriniella mangrovei* and *Khuskia oryzae* and two parasite species *viz.*, *Pestalotiopsis agallochae* and *Cladosporium marinum* (Punarbasu and Santra, 2013).

OCCURRENCE AND DISTRIBUTION OF MANGROVE FUNGI

Mangroves are biodiversity "hotspots" for fungi because the bases of mangrove trunks and aerating roots are permanently or intermittently submerged. Terrestrial fungi and lichens occupy the upper part of the trees and roots that are rarely or never reached by salt water, whereas marine fungi occupy the lower parts of roots and trunks that are exposed to seawater. At the interface, there is an overlap between marine and terrestrial fungi (Sarma and Hyde, 2001). The mangrove fungi are the second largest group among the marine fungi (Hyde, 1990). They occur not only in water and soil, but also as parasites on plants and animals as well as symbionts in marine lichens, plants, and algae.

The wood-inhabiting fungi are termed as 'lignicolous fungi', constituting over 50% of the total marine fungi recorded so far in India. About 150 species are present only on decaying mangrove wood, aerial roots, and seedlings, and they mostly are coming under the class of *Ascomycetes*. The lignicolous fungi are quite abundant in mangrove ecosystems, due to easy availability of wood as their bait (Kalaiselvam, 2015).

The endophytic fungi constitute the second largest group of marine fungi after the lignicolous fungi (Kohlmeyer and Kohlmeyer, 1979). The fungal endophytes are micro-fungi, contributing to mangrove fungal diversity with a record of over 200 species, mostly belonging to the family Ascomycetes (Sridhar *et al.*, 2012). They colonize the internal tissues of mangrove plants without producing any apparent disease symptoms, and they provide protection to the mangrove plants against environmental extremes and help in decomposition after senescence of the plant parts. The endophytic fungi are well-known for the production of bioactive substances (Gayathri *et al.,* 2010).

Mangrove soil especially in the rhizosphere has more counts of fungi and yeasts than water. Fungal counts in rhizosphere soil are maximum in monsoon and minimum during summer. The fungal counts are higher on mangrove leaf litter than on fresh leaves. Higher counts are found to be dependent on biochemical composition of mangrove species. *Avicennia* species with low levels of tannins and high levels of amino acids favours fungal colonization over *Rhizophora* species with high levels of tannins and low levels of amino acids (Ravikumar and Kathiresan, 1993; Kathiresan, 2000a; Kathiresan *et al.*, 2012). The fungal biodiversity in the mangroves reflects the maturity of the plants. A well-developed mangrove habitat provides a larger number of fungal species than the new mangrove sites (Kathiresan, 2012).

ECOLOGICAL ROLE OF MANGROVE FUNGI

Fungi are the first invaders, in the early phases of decomposition of mangrove litters such as leaves, stems, roots, flowers, fruits and wood. The tannins leach out of the litters and are degraded by fungi but are toxic to bacteria. After sufficient leaching of tannins from mangrove litter, bacteria colonize the litter for further decomposition (Rajendran and Kathiresan, 2007). Mangrove wood debris are decomposed by the enzymes of lignicolous fungi and further by shipworms, which feed on lignicolous fungi, without which the shipworms cannot reproduce. These decomposition process releases nutrients, thereby enriching the mangrove habitat and other associated coral reefs, seaweeds, and seagrass beds. The detritus is microbially decomposed organic matter and protein-rich food product, thereby serving as a nutritious food for fishes. The nutrients that are released during litter decomposition help in proliferation of phytoplankton which is consumed by zooplankton, small fishes and larger fishes, thereby operating the food web in the coastal sea, as proved by using stable isotopes (Nabeel *et al.*, 2010; Kathiresan, 2012; 2019).

BIOPROSPECTING POTENTIAL OF MANGROVE FUNGI

Mangrove fungi have bioprospecting potential (Kalaiselvam, 2015; Kathiresan 2020). They are known to produce exopolysaccharides, Ca^{2+}-gluconic acid, polymalate, liamocin, polyunsaturated fatty acids, biofuels, xylitol, enzymes, and bioactive substances, which have many potential applications in the bioenergy, food, agricultural, and pharmaceutical industries (Jia *et al.*, 2020).

Polythene and plastic-degrading mangrove fungi

A fungal species (*Aspergillus glaucus*) isolated from mangrove soil is proved to be efficient in degrading 29% of polythene and 7% of plastics within a month time (Kathiresan, 2003).

Dye degradation by mangrove fungi

Mangrove fungi are capable of degrading synthetic dyes. About 89% of malachite green is known to be degraded by laccase enzyme, derived from *Hypocrea lixii* within 10 days. The undegraded dye is highly toxic, while the degraded dye is non-toxic, as proved by biotoxicity assay with *Artemia salina* (Saravanakumar, 2012).

Removal of Toxic Metals by Mangrove fungi

The fungal dry biomass of *Hypocrea lixii* is reportedly efficient to remove 94% of lead within 47 min and 88% of iron within 34 min (Saravanakumar, 2012).

Mangrove-derived enzymes

Mangrove fungi are known for enzyme production (Saravanakumar *et al.*, 2016). Glucose oxidase has practical application in food industries and clinical sectors. Starch-degrading amylase is of great importance in food, fermentation, textile, and paper industries. Cellulase finds application in bio-bleaching of pulp, treatment of wastewater and recycling of wastepaper in pulp industries. Glucose isomerase is useful in production of sweetener, as an alternative to sugar. Alkaline protease is primarily used as detergent additive, holding more than 50% of total enzyme market.

All the above-said enzymes are produced by *Penicillium fellutanum* isolated from mangrove soil (Manivannan and Kathiresan, 2007a, b; Kathiresan and Manivannan, 2006a, b, c; 2007).

The marine yeasts of mangrove soil are efficient in the production of invertase enzyme of industrial importance for converting the sucrose into glucose and fructose and glucosidase of antidiabetic effect for digesting the carbohydrates and processing the glycoproteins and lipids. The yeast extract can also serve as an immune stimulator for increasing total haemocytes, phenoloxidase, and endobiotics in haemolymph of the shrimp exposed to pathogenic vibrios (Manivannan, 2008).

Among the mangrove fungi, *Trichoderma* species are much efficient in producing enzymes such as amylase, cellulase, protease, lipase and chitinase. These enzymesare important for litter decomposition process to occur in mangrove ecosystems (Kathiresan *et al.*, 2010). The protease derived from *Trichoderma estonicum* is capable of removing blood stain by 60% instantly, which is greater than that of the commercial detergent (Saravanakumar and Kathiresan, 2012). Thermostable cellulase derived from *Trichoderma* (*Hypocrea estonica*) is a potent enzyme for the conversion of the lignocellulosic waste (sawdust) into the simple sugars (Saravanakumar, 2012).

The fungus *Trichoderma* isolated from mangrove soil is capable of phosphate solubilization and phytase enzyme production. It is also proved that the fungal treatment improves the mangrove soil fertility as well as growth and biomass production of seedlings of *Avicennia marina* (Saravanakumar *et al.*, 2013).

Artificial honey using yeasts

Our laboratory has made a break-through in making artificial honey using yeast cells. We have isolated the yeast cells from the salivary glands of the honeybee, *Apis cerana*, which is abundant in mangrove areas, and inoculated in sucrose solution under agitation in laboratoryconditions. The solution exhibits increased levels of fructose and total amino acids. The solution after 48 h becomes brown in colour, similar to the natural honey (Kathiresan and Srinivasan, 2006).

Bioethanol production using yeasts

Our laboratory has proved that mangrove-derived marine yeast strains (*Saccharomyces cerevisiae* and *Pichia salicaria*) are promising for bioethanol production over the terrestrial yeast (Kathiresan and Saravanakumar, 2011; Saravanakumar *et al.*, 2013). *Candida albicans* exhibits a high ethanol production up to 47.3% (3.1 g/L) within 96 h, when glucose is used as carbon source. This species produces increased level of bioethanol when the yeast cells are immobilized in sodium alginate (Senthilraja and Kathiresan, 2015).

Sawdust, a lignocellulosic waste material, can be used for achieving the bioethanol production of up to 85.6% (55.2 g/L) under the optimized conditions of temperature of 36.5 °C, incubation time of 102 h, hydrolysed sawdust of 45.14 ml/L and agitation of 330 rpm (Saravanakumar and Kathiresan 2012; 2014). A similar observation is made with the mangrove-derived fungi and yeast cells that produce high yield of ethanol in shaking fermentation than the stationary fermentation when the saw dust is enzymatically saccharified using *Aspergillus ochraceus* and fermented by *Sacchromyces cerevisiae* (Sathiya *et al.*, 2014).

Nanoparticle synthesis

Aspergillus niger isolated from mangrove soil is capable of reducing the silver ions to nanoparticles at a faster rate. The silver nanoparticles are also found to inhibit human pathogenic bacteria and fungi. Similarly, the yeast *Pichia capsulata* produces silver nanoparticles, within minutes. The yeast protein with molecular weight of 70 kDa is responsible for nanoparticle synthesis (Kathiseran *et al.*, 2010). *Penicillium fellutanum* isolated from mangrove soil is able to produce silver nanoparticles within minutes (Kathiresan *et al.*, 2009). Similarly, mangrove-derived *Trichoderma hamatum*, exhibits the synthesis of silver and gold nanoparticle (Saravanakumar, 2012). The endophytic fungus *Aspergillus terreus* is reported to induce the synthesize of silver nanoparticles and these are also proved to have antidermatophytic activity against human skin fungi (Sathiya *et al.*, 2013). The mangrove-based nanoparticles are proved to have different biological activities in stabilizing the cotton fabrics and making them odour resistant, preserving the apple fruits, purifying the drinking water from microbial contaminants, inhibiting the human pathogenic bacteria, controlling vibriosis disease, detoxifying the carcinogenic ethidium bromide as well as in killing the cancer cells that cause oral and skin cancers (Kathiresan *et al.*, 2012; Asmathunisha and Kathiresan, 2013).

Antimicrobial activity of mangrove fungi

Mangrove-derived *Trichoderma* species are found to have antimicrobial activity against human and fish pathogens (Narendran and Kathiresan, 2016). Similarly, *Trichoderma atroviride* is proved to have antibacterial and antioxidant potentials (Saravanakumar *et al.*, 2018). Mangrove-derived yeast, *Saccharomyces cerevisiae* is found to produce an antimicrobial protein against human pathogens (Senthilraja *et al.*, 2015). Similarly, the endolichenic fungi isolated from mangrove environment are shown to have antagonistic activity against human pathogens (Logesh *et al.*, 2012).

ANTI-CANCER ACTIVITY OF MANGROVE FUNGI

Trichoderma atroviride produces novel metabolites against human prostate cancer cells. The copper oxide nanoparticles synthesised by fungi are reported to cause photothermolysis on human lung cancer (Saravanakumar *et al.*, 2019). *Fusarium oxysporum* isolated from a mangrove hybrid species (*Rhizophora annamalayana*) is shown to produce anticancer taxol compounds (Elavarasi *et al.*, 2012).

CONCLUSION

The mangrove fungi are promising for novel chemical entities, enzymes, and bioactive substances (Jia *et al.*, 2020)**;** but, remain largely untapped. For example, glycolipids are of various applications in various industries dealing with bioremediation of hydrocarbons, food, cosmetics, biocontrol, and pharmaceutical industries. The glycolipids are mostly the important constituent of cell membrane in marine fungi, and they are structurally unique with efficient biological activities, as compared to those of terrestrial fungi. But the glycolipids are least studied for marine fungi, and no specific study on glycolipids of mangrove fungi is available. Hence, this review calls for an urgency of studying such valuable biomolecules from mangrove fungi.

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