AUCTORES
Globalize your Research

Journal of Pharmaceutics and Pharmacology Research
Waill A. Elkhateeb *

Open Access

Review Article

Endophyte Fungi from Agarwood and Mangrove and Their Applications

Waill A. Elkhateeb*, Dina E. El-Ghwas, Ghoson M. Daba

Chemistry of Natural and Microbial Products Department, Pharmaceutical Industries institute, National Research Centre, Dokki, Giza, 12622, Egypt.

***Corresponding Author:** Waill A. Elkhateeb, Chemistry of Natural and Microbial Products Department, Pharmaceutical Industries institute, National Research Centre, Dokki, Giza, 12622, Egypt.

Received date: March 06, 2023; **Accepted date:** March 13, 2023; **Published date:** March 23, 2023

Citation: Waill A. Elkhateeb, Dina E. El-Ghwas and Ghoson M. Daba, (2022). Endophyte Fungi from Agarwood and Mangrove and Their Applications, *J. Pharmaceutics and Pharmacology Research*, 6(3); **DOI:**10.31579/2693-7247/123

Abstract

Mangroves are woody trees or shrubs salt marsh halophytes that encompass over 75% of the tropical coastline on the planet. Mangroves are characterized by their sophisticated morphological and physiological adaptations as well as their rich synthesis of biologically active secondary metabolites. They also contribute in decreasing CO2 levels in the atmosphere through photosynthesis. On the other hand, agarwood, is an aromatic perfumed precious heartwood of diseased timber of Aquilaria and Gyrinops trees that is used centuries ago till now as incense in religious ceremonies, raw material in the perfume industry and as a medicine. Agarwood formation is usually induced by wounding trunks and branches of Aquilaria trees. Production of natural agarwood resin is inefficient and don't meet global demand, so different methods have been applied to stimulate biological agarwood induction, and using endophytic fungi is one of the methods. Hence, this review highlights the importance of endophytic fungi in mangroves and agarwood, their existence and some of their important biological activities.

Key words: endophyte fungi; agarwood; mangrove; biological activities

Introduction

Mangroves are salt marsh halophytes that are either woody trees or shrubs. 121 nations are home to the mangrove flora. The Mangrove ecosystem refers to the particular areas where mangrove plants flourish. From 6500 B.C., mangrove forests have been valued for their long-lasting benefits, which have been proven by archaeological evidence. Mangroves are salt-tolerant plant species that grow in estuarine ecosystems and river deltas in tropical and subtropical areas along intertidal zones of rivers and seas in the shape of wide patches or narrow strips. With greater freedom, mangrove species are rapidly dwindling in number [1]. Mangrove forests are found everywhere along the coasts of third-world countries, covering an area of 14 million square miles worldwide. Mangroves encompass over 75% of the tropical coastline on the planet. Together, the western Pacific and Indian Oceans make up 20% of the world's total area of mangroves [2].

Because the mangrove ecosystem is always under stress, which results in the creation of certain substances for their survival, mangrove forests are significant productive tropical ecosystems with high biodiversity [3,4]. Because of the ongoing evolutionary fight for survival, it has been previously suggested that biological diversity would entail chemical diversity [5]. As a result, in addition to their sophisticated morphological and physiological adaptations, the synthesis of bioactive secondary metabolites may be crucial in the ongoing fight between mangroves and other plants, animals, and microorganisms for the scarce resources in their habitat. In fact, despite the fact that comprehensive study on mangrove metabolites has only just emerged, the ability of mangroves to produce a wide variety of bioactive substances is reflected in a number of articles which explain the significant chemical diversity of their metabolites [6,7].

The *Rhizophoraceae, Acanthaceae, Lythraceae, Verbenaceae, Combretaceae*, and *Arecaceae* families of shrubs and trees dominate mangrove forests [8]. According to several of these families, *Rhizophora mangle* (Rhizophoraceae), *Laguncularia racemose* (*Combretaceae*), and *Avicennia schaueriana* (Verbenaceae), respectively, mangroves in Brazil are categorized as red, white, or black mangroves. The leaves of *Rhizophora mucronata* are broadly elliptic to rectangular, and its flowers have yellowish stalks [11,12]. The connection of fungi as endophytes with mangrove roots has been hypothesized to provide protection from unfavourable environmental factors and to enable the latter to successfully compete with saprophytic fungi that destroy senescent roots [13]. Moreover, mangrove forests are regarded as an open interface ecosystem that links highland terrestrial and coastal estuarine environments, and the endophytic fungi in mangroves are a conglomerate of freshwater, marine, and soil fungi [13,14]. Moreover, endophyte assemblage varies with the host plant's age, different seasons, and different sections (leaves, twigs, roots) [15].

Nonetheless, *Avicennia* species made inexpensive and nourishing feed for camels, buffaloes, sheep, and goats. These animals are permitted to graze in mangrove habitats, and camels in particular are occasionally taken to uninhabited islands with dense mangrove cover. In Indonesia, the Pakistani Gulf, and India, this is quite typical [16]. Tolerance to various conditions like salt, oxidative stress, hyperosmotic stress, drought, and nutritional stress, for instance, may be conferred by them [17–19]. Several ailments are treated with mangroves in traditional medicine [20]. They were utilized for food, energy, medicine, and leather tanning [21]. According to Kathiresan 2012, mangrove extracts may be able to treat human, animal, and plant infections as well as chronic viral diseases like AIDS [22]. Mangroves are recognized to play a part in removing CO_2 from the atmosphere through photosynthesis, which may have lessened the issues with "Greenhouse gases" and global warming, according to Kathiresan and Bingham in 2001 [23].

Fungi

Every ecosystem needs fungi because they play a critical role in activities including nutrient recycling, decomposition, and movement across diverse settings. Only a small portion (about 5%) of the over a million distinct fungus species thought to exist on Earth have been recognized [24]. About 120 fungal species, including 87 *ascomycetes*, 31 *mitosporic* fungus, and 2 *basidiomycetes*, were reported by Hyde in 1990 as colonizing 29 mangrove plants around the world [25]. One of the most prevalent characteristics of mangrove forests is the zonation phenomena. It has been reported that 625 mangrove-associated fungus, comprising 279 *Ascomycetes*, 277 *Mitosporic* fungi, 29 *Basidiomycetes*, 3 *Chytridiomycetes*, 2 *Myxomycetes*, 14 *Oomycetes*, 9 *Thraustochytrids*, and 12 *Zygomytes*, exist. One of the crucial microbiological elements of plants is fungi. Along with other microorganisms, it forms a crucial component of the ecosystem [28,29]. Manglicolous fungi are mangrove-specific fungus. They are crucial for the cycling of nutrients and can produce all the enzymes needed to break down lignin, cellulose, and other plant materials [30–31]. The variety of fungus species and their seasonal appearance on mangrove seedlings are found on mangroves from all over the world [32]. In the mangrove ecosystem, fungi can be found as saprophytes, symbiotic partners, or parasites. These fungi are divided into two classes: the lower class, which includes *Oomycetes* and *thraustochytrids*, and the upper class, which includes *ascomycetes* and *basidiomycetes*. Secondary metabolites produced by fungi have a wide range of structural variations, and they frequently serve as a form of self-defence against other microbes. Mangrove fungus are typically found adorning difficult settings, providing them a rich source of bioactive compounds [33].

Endophytic fungi

A class of fungus known as endophytic fungi infiltrate the interior and live tissues of plants without immediately manifesting any detrimental effects [34]. Endophytes are obtained from fungus, bacteria, or internal, symptomless plant tissues. Although it creates no visible signs of disease, it targets the tissues of living plants and causes infections that are fully contained within plant tissues [35]. Many investigations on the fungus living in mangroves along the coastlines of the Indian, Pacific, and Atlantic Oceans have been done since Cribb first identified endophytic fungi isolated from mangrove roots in 1955 [36].

According to phylogenetically determined classifications, endophytic fungi fall under the *Ascomycota*, *Basidiomycota*, and *Zygomycota* groups [37]. *Trichoderma ascomycetes* were originally discovered in mangrove habitats in Brazil, China, and Indonesia in 1920, and they have just recently been published in the literature. *Trichoderma* spp., which are well-known biocontrol agents against diseases of cultivated plants, also exhibit an increased ability of hazardous chemical breakdown in plants, soil, and water [38]. *Trichoderma* spp. colonizes its hosts quickly, produces a lot of free-living, green spores, and has fruiting bodies that help to characterize this genus' fungi [39]. Another filamentous fungus with branched mycelium bodies is *Zygomycetes* of *Rhizopus* genus, which was discovered in a mangrove area of Nigeria. It is mostly employed as a source of enzymes for the breakdown of organic contaminants and in conventional food fermentation processes [40,41]. The *basidiomycete* phylum includes the filamentous fungus *Schizophyllum commune*, which was isolated from an Indian mangrove forest. Its fruiting bodies and pale to light greyish/brown colonies make it easier to identify. It possesses antiviral and anticancer properties and is utilized in the synthesis of pigments [42].

In various nations throughout the world, the diversity of endophytic fungi has been investigated primarily on the barks, branches, leaves, stems, and roots of mangrove plant species in order to determine their biological activity. It is well recognized that endophytic fungi are a rich source of bioactive substances, including medicines and enzymes. Endophytic fungi represent a new source for getting enzymes with various potentialities because they are a relatively untapped field in microorganism isolation. Over one million endophytic species are found throughout all plants, and endophytic fungi are one of these endophytes that live inside the plants without manifesting any symptoms [43].

Biological activities of mangroves endophytic fungi

Because of their immense capacity to create bioactive substances, endophytes are becoming more and more significant. In mangrove fungi, which have led to the discovery of numerous novel bioactive compounds with significant nutraceutical and medicinal applications, endophytes play a crucial role. Together with other pharmaceuticals, these include antibiotics, anticancer, antidiabetic, antioxidant, antiviral, anti-inflammatory, and immunosuppressive medications. Because of their immense capacity to create bioactive substances, endophytes are becoming more and more important. The choice of natural sources is one of the most important elements of a successful natural product-based drug development program. Despite the limited amount of research on the chemistry of mangrove endophytes, more than 200 species of endophytic fungi have been isolated and identified from mangrove trees and have already been shown to be a reliable source for structurally diverse and biologically active secondary metabolites [44]. Endophytic fungi were considered to be new sources of active chemicals, biological activity, and biotechnological advancements; yet, their full potential has yet to be fully realized [45]. When compared to other plant parts, leaves typically exhibit a more diversified fungal endophytes community [46,47]. Significant biological activities for endophytic fungi that originate from mangrove leaves [48–50].

The most common cultivable endophytic fungi in mangroves have been identified as *Alternaria, Aspergillus, Cladosporium, Clolleto-trichum, Fusarium, Paecilamyces, Penicillium, Pestalotiopsis, Phoma, Phomopsis, Phyllosticta*, and *Trichodema* [51]. Several studies were shown on microorganisms associated with *R. mucronata*, including fungal endophytes. An earlier study in secondary metabolites of endophytic fungi from mangroves visible that the fungi produced antibiotic like Griseofulvin, which is generally found in *Penicillium griseofulvum* [52] on the plant itself. While various isolates of *R. mucronata*, including *Penicillium*, *Ampelomyces*, and Fusarium, were shown to be effective against *E. coli*, isolates of *R. apiculata* resulted in the discovery of new chemicals like acropyrone, bicytosporone D, waol acid, and pestalotiopene [53,54]. Alkaloids, terpenes, coumarins, quinones, anthraquinones, quinones, quinones, peptides, phenolic acids, and lactones are some of the secondary metabolites of mangrove endophytic fungi. From *Pestalotiopsis* sp., halotolerant *Rhizophora stylosa* was isolated, and it has the ability to produce lignin-degrading enzymes. As a result of their existence, *Alternaria, Aspergillus, Cladosporium, Colletotrichum, Fusarium, Paecilomyces, Penicillum, Pestalotiopsis, Phoma, Phomopsis, Phyllosticta,* and *Trichoderma* have been identified as the main cultivable mangrove endophytic fungi [55].

Agarwood

Agarwood, a precious natural product (Widely used as incense in religious ceremonies, raw material in the perfume industry and a medicine for treating sedative, analgesic and digestive problems for thousands of years), can be defined as aromatic perfumed dark resinous heartwood of diseased timber of *Aquilaria* and *Gyrinops.* Agarwood has been used for thousands of years in several countries as incense, perfumes, and multifunctional pharmaceutical product. The main compounds in agarwood include Sesquiterpenes, 2-(2-phenylethyl)-4H-chromen-4-one and its derivatives (PeCs), Aromatics, Triterpenes and five other categories [56].

Traditionally, agarwood formation is induced by wounding, holing, nailing, and chopping the trunks and branches of *Aquilaria* trees. According to the latest hypothesis, agarwood formation is due to plant defence [57]. When an *Aquilaria* tree is wounded, damage signals are induced and transmitted to activate the defence response, which subsequently leads to the production of defensive substances such as sesquiterpenes and phenylethyl chromone derivatives [57]. Natural agarwood resin production is inefficient and yields are low; thus, it is difficult to meet global demand, so different methods have been applied to stimulate biological agarwood induction, and the use of endophytic fungi is one of the methods [57].

Agarwood endophytic fungi

Endophytic fungi have been isolated from several parts of *Aquilaria*, and some of them show evidence for inducing agarwood formation. Gong & Guo [58], isolated endophytic fungi from leaf, root and stem tissues of *Aquilaria sinensis* and found that most abundant endophytic fungus is *Mycelia sterilia* (14.3%) followed by *Fusarium* sp. (7.1%), *Cladosporium edgeworthrae* and *Glomerularia* sp. (5.7%). Some fungal strains are known for antimicrobial activities, but the role of fungal endophytes in the formation of agarwood was not explored. Mohamed et al. [59], showed that a wounded stem of *Aquilaria malaccensis* contained *Fusarium* sp. (46%) and *Lasiodiplodia* sp. (35%), both of which are mainly responsible for agarwood production followed by *Trichoderma* sp. (13%).

Biological activities of agarwood endophytic fungi

Cui et al. [60], found that endophytic *Fusarium* and *Phaeoacremonium* species are the dominant genera in the stem of *A. sinensis*, and *Phoma herbarum* and *Fusarium equiseti* show promising antimicrobial activities, while *Xylaria mali*, *Phaeoacremonium rubrigenum* and *Lasiodiplodia theobromae* show high antitumor activity [60].

Twenty-eight fungal endophytes were isolated from agarwood by strict sterile sample preparation and were classified into 14 genera and 4 taxonomic classes (Sordariomycetes, Dothideomycetes, Saccharomycetes, and Zygomycetes) based on molecular identification. Of the 28 isolates, 13 (46.4%) showed antimicrobial activity against at least one of the test strains by the agar well diffusion method, and 23 isolates (82.1%) displayed antitumor activity against at least one of five cancer cell lines by 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay. The diameters of inhibition zones of YNAS07, YNAS14, HNAS04, HNAS05, HNAS08, and HNAS11 were equal to or higher than 14.0 mm against *Staphylococcus aureus, Escherichia coli*, *Bacillus subtilis, B. subtilis, Aspergillus fumigatus,* and *B. subtilis*, respectively. The inhibition rates of YNAS06, YNAS08, and HNAS06 were not less than 60% to 293-T, 293-T, and SKVO3 cells, respectively [60]. Cui et al., [60], results that the endophytic fungi associated with agarwood will provide us with not only useful micro-ecological information, but also potential antimicrobial and antitumor agents.

Agarwood is the most expensive non-construction wood product in the world. As a therapeutic agent, agarwood can cure some diseases, but few studies have been carried out on the antagonistic abilities of endophytic fungi associated with agarwood. Agarwood is mainly found in the genus *Aquilaria* [61]. 47 endophytic strains were selected to check their bioactivities against three bacterial pathogens viz. *Erwinia amylovora, Pseudomonas syringae*, and *Salmonella enterica*; and three fungal pathogens viz. *Alternaria alternata*, *Botrytis cinerea*, and *Penicillium digitatum*. The 47 strains selected, 40 strains belong to 18 genera viz. *Alternaria*, *Annulohypoxylon*, *Aspergillus*, *Botryosphaeria*, *Colletotrichum*, *Corynespora*, *Curvularia*, *Daldinia*, *Diaporthe*, *Fusarium*, *Lasiodiplodia*, *Neofusicoccum*, *Neopestalotiopsis*, *Nigrospora*, *Paracamarosporium*, *Pseudopithomyces*, *Trichoderma*, *Trichosporon* and one strain belongs to Xylariaceae had antimicrobial activities. In particular, *Lasiodiplodia* sp. (YNA-D3) showed the inhibition of all the bacterial and fungal pathogens with a significant inhibition rate. In addition, the strains viz; *Curvularia* sp. (GDA-3A9), *Diaporthe* sp. (GDA-2A1), *Lasiodiplodia* sp. (YNA-D3), *Neofusicoccum* sp. (YNA-1C3), *Nigrospora* sp. (GDA-4C1), and *Trichoderma* sp. (YNA-1C1) showed significant antimicrobial activities [61].

Conclusion

Studying the endophytic fungi existing on mangroves and agarwood can contribute in further understanding of their importance and role in protection or induction of these ecosystems. Moreover, the secondary metabolites produced by these endophytic fungi are a rich source that can contribute in increasing potency of some currently used drugs or even the invention of new drugs. Databases should be made to contain all reported data concerning these fungi, their metabolites and their biological activities in order to facilitate providing researchers with updated information which will save time and effort.

References

1. Bandaranayake WM. (1998). Traditional and medicinal uses of mangroves. Mang and Salt Marsh. 2: 133-148.
2. Debbab A, Aly AH and Proksch P. (2013). Mangrove derived fungal endophytes a chemical and biological perception. Fungal Diversity, 61-61.
3. Bandaranayake WM. (2002). Bioactivities, bioactive compounds and chemical constituents of mangrove plants Wetlands Ecology and Management, 10: 421-452.
4. Macintosh DJ, Ashton EC. (2002). A review of mangrove biodiversity conversation and management MCB (2002).
5. Strobel G, Daisy B, Castillo U, Harper J. (2004). Natural products from endophytic microorganisms. J. Nat. Prod. 67(2): 257-268.
6. Wu J, Xiao Q, Xu J, Li MY, Pana JY, Yang M. (2008). Natural Product Report; 25: 955-981.
7. Li D, Li X, Li TG, Dang HY, Proksch P, Wang BG. (2008). Benzaldehyde derivatives from *Eurotium rubrum*, an endophytic fungus derived from the mangrove plant *Hibiscus tiliaceus*. Chem. Pharm. Bull. 56(9): 1282-1285.
8. Rafferty JP. (2011). Lakes and Wetlands South America.
9. Francisco PM, Tambarussi EV, de Alves FM, Bajay S, Ciampi-Guillardi M, Souza AP. (2018). Genetic diversity and mating system of rhizophora mangle l. (rhizophoraceae) in Northern Brazil revealed by microsatellite analysis. Cerne, 24: 295-302.
10. Silva JM, Martins MB, Cavalheiro AJ, (2010). Caracterização anatômica e perfis químicos de folhas de Avicennia schaueriana Stapf. & Leech. ex Moldenke e Rhizophora mangle L. de manguezais impactados e não impactados do litoral paulista. Insul. Rev. Botânica, 39: 14-33.
11. Qin H, Boufford DE. (2007). Rhizophoraceae. Flora of China; 13: 295.
12. Setyawan AD, Ulumuddin YI. (2012). Species diversity of *Rhizophora* in Tambelan Islands, Natuna Sea, Indonesia. Biodiversitas, 13: 172-177.
13. Anada K, Sridhar KR. (2002). Diversity of endophytic fungi in the roots f mangrove species on the west coast of India, Can. J. Microbiol. 48: 871-878.

14. Sengputa A, Chaudhuri S. (2002). Arbuscular mycorrhizal relations of mangrove plant community at the Ganges River estuary in India. Mycorrhiza 12: 169-174.
15. Pang K-L, Vrijmoed LL, Goh TK, Plaingam N, Jones GE. (2008). Fungal endophytes associated with Kandelia candel (Rhizophoraceae) in Mai Po Nature Reserve, Hong Kong. Botanica Marina 51, 171-178.
16. Kirtikar KR, Basu BD. (1991). Indian medicinal plants. Lalit Mohan Basu Publishers, Allahabad, India: 1-2793 I-IV.
17. Cheng ZS, Pan JH, Tang WC, Chen QJ, Lin YC. (2009). Biodiversity and biotechnological potential of mangrove-associated fungi. Journal of forestry Research; 20-21.
18. Xu J. (2015). Bioactive natural products derived from mangrove-associated microbes. RSC Advances; 5(2): 841-892.
19. Zhou J, Diao X, Wang T, Chen G, Lin Q, Yang X, Xu J. (2018). Phylogenetic diversity and antioxidant activities of culturable fungal endophytes associated with the mangrove species *Rhizophora stylosa* and *R. mucronata* in the South China Sea. PLOS One; 13(6): 1-18.
20. Kirtikar KR, Basu BD. (1991). Indian medicinal plants. Lalit Mohan Basu Publishers, Allahabad, India: 1-2793 I-IV.
21. Tan TK, Pek CL. (1997). Tropical mangrove leaf litter fungi in Singapore with an emphasis on Halophytophthora. Mycological Research; 101: 165-168.
22. Kathiresan K. (2012). Importance of mangrove rcosystem. Int Journal of Marine Science; 2(10): 70-89.
23. Kathiresan K, Bingham BL. (2001). Biology of mangroves and mangrove ecosystem. Hindustan Publishing Corporation. New Delhi, 251.
24. Hawksworth DL. (1991). The fungal dimension of biodiversity, magnitude, significance and conservation. Mycological Res; 95: 641-55.
25. Hyde KD. (1990). A comparison of the intertidal mycota of five mangrove tree species. Asian Marine Biol; 7: 93-107.
26. Schmit JP, Shearer CA. (2003). A checklist of mangrove-associated fungi, their geographical distribution and known host plants. Mycotaxon; 85: 423-477.
27. Liu AR, Wu XP and Xu T. (2007). Research advances in endophytic fungi of mangrove. The journal of applied ecology; 18(4): 912-918.
28. Hyde KD. (1990). A comparison of the intertidal mycota of five mangrove tree species. Asian Marine Biol; 7: 93-107.
29. Harrison PJ, Snedaker SC, Ahmed SI. (1994). Primary producers of the arid climate mangrove ecosystem of the Indus River Delta, Pakistan: an overview. Tropical Ecology; 35(2): 155-184.
30. Fell JW, Master IM, Wiegert RG, Snedaker SC, Snedaker JG. (1984). Litter decomposition and nutrient enrichment in the mangrove ecosystem research methods monograph on oceanography methodology. UNESCO Paris; 8: 239-251.
31. Findlay RH, Fell JW, Coleman NK, Vestal JR. (1986). Biochemical indicators of the role of the fungi and thraustochytrids in mangrove detrital systems In moss ST ed The biology of marine fungi. Cambridge University Press Cambridge; 91-104.
32. Mehdi FS, Saifullah SM. (2000). Species diversity and seasonal occurrence of fungi on seedlings of Avicennia marina (Forsk.) Vierh. Pakistan Journal of Biological Sciences; 3(2): 265-268.
33. Sun HH, Mao WJ, Chen Y, Guo SD, Li HY, Qi XH, Chen YL, Xu J. (2009). Isolation chemical characteristics and antioxidant properties of the polysaccharides from marine fungus *Penicillium* sp. Carb Polym; 78: 117-124.
34. Hirsch GU, Braun U. (1992). Communities of parasitic microfungi in Winterhoff W ed Handbook of Vegetation Science. Fungi in vegetation science. 19: Dordrecht, Netherlands, Kluwer Academic; 225-250.
35. Wilson AD. (1995). Endophyte-the evolution of the term, a clarification of its use and definition. Oikos; 73: 274-276.
36. Cribb AB, Cribb JW. (1955). Marine fungi from Queensland. Brisbane. University of Queensland Press. Department of Botany; 3: 97-105.
37. Rajesh RW, Rahul MS, Ambalal NS. (2016). *Trichoderma*: A significant fungus for agriculture and environment. Afr. J. Agric. Res. 11: 1952–1965.
38. Adnan M, Islam W, Shabbir A, Khan KA, Ghramh HA, Huang Z, Chen H, Lu G-G. (2019). Plant defense against fungal pathogens by antagonistic fungi with Trichoderma in focus. Microb. Pathog.
39. Luo J, Xiao X, Luo SL. (2010). Biosorption of cadmium (II) from aqueous solutions by industrial fungus *Rhizopus cohnii*. Trans. Nonferrous Met. Soc. China, 20: 1104–1111.
40. Petruzzello, M. Rhizopus|Fungus Genus|Britannica. Encycl. Br. (2016). Available online: https://www.britannica.com/science/Rhizopus (accessed on 22 December 2020).
41. Biasetto C, Somensi A, Figueiro F, De Moraes L, Silva GH, Marx Young MC, Da Silva Bolzani V, Araújo AR. (2019). Diketopiperazines and arylethylamides produced by Schizophyllum commune, an endophytic fungus in *Alchornea glandulosa*. Eclet. Quim., 44: 36–42.
42. Costa IP, Maia LC, Cavalcanti MA. (2012). Diversity of leaf endophytic fungi in mangrove plants of Northeast Brazil. Braz. J. Microbiol., 43: 1165–1173.
43. Carrim AJ, Barbosa EC, Vieira JDG. (2006). Enzymatic activity of endophytic bacterial isolates of Jacaranda decurrens Cham. (Carobinha-do-campo). Braz. Arch. Biol. Technol.; 49: 353-359.
44. Li MY, Xiao Q, Pan JY, Wu J. (2009). Natural products from semi-mangrove flora: source, chemistry and bioactivities. Nat. Prod. Rep. 26(2): 281-298.
45. Tan RX, Zou WX. (2001). Endophytes: a rich source of functional metabolites. Nat Prod Rep. 18: 448-459.
46. Bayman P, Lebron LL, Tremblay RL, Lodge DJ. (1997). Variationin endophytic fungi from roots and leaves of *Lepanthes Orchidaceae*. New Phytol; 135: 143-149.
47. Shreelalitha SJ, Sridhar KR. (2015). Endophytic fungi of wild legume *Sesbania bispinosa* in coastal sand dunes and mangroves of the Southwest coast of India. J For Res., 26: 1003-1011.
48. Chaeprasert S, Piapukiew J, Whalley AJ, Sihanonth P. (2010). Endophytic fungi from mangrove plant species of Thailand: their antimicrobial and anticancer potentials. Bot Mar., 53: 555-264.
49. Abraham S, Basukriadi A, Pawiroharsono S, Sjamsuridzal W. (2015). Insecticidal activity of ethyl acetate extracts from culture filtrates of mangrove fungal endophytes. Microbiology, 43: 137-149.
50. Thomas SA, Fleming L, Shaw R, Baker BJ. (2016). Isolation of bioactive secondary metabolites from mangrove fungal endophytes using epigenetic regulation. Planta Med., 82: S1-S381.
51. Liu AR, Wu XP, Xu T. (2007). Research advances in endophytic fungi of mangrove. The journal of applied ecology, 18(4): 912-918.
52. Klaiklay S, Rukachaisirikul V, Tadpetch K, Sukpondma Y, Phongaichit S, Buatong J, Sakayaroj J. (2012). Chlorinated chromone and diphenyl ether derivatives from the mangrove-derived fungus Pestalotiopsis sp. PSU-MA69. Tetrahedron, 68(10): 2299-2205.

53. Prihanto A, Firdaus A, Nurdiani R. (2011). Endophytic fungi isolated from mangrove (*Rhizophora mucronata*) and its antibacterial activity on *Staphylococcus aureus* and *Escherichia coli*. J Food Sci Eng., 1: 386-89.
54. Klaiklay S, Rukachaisirikul V, Tadpetch K, Sukpondma Y, Phongaichit S, Buatong J, Sakayaroj J. (2012). Chlorinated chromone and diphenyl ether derivatives from the mangrove-derived fungus Pestalotiopsis sp. PSU-MA69. Tetrahedron, 68(10): 2299-2205.
55. Zhou J, Diao X, Wang T, Chen G, Lin Q, Yang X, Xu J. (2018). Phylogenetic diversity and antioxidant activities of culturable fungal endophytes associated with the mangrove species *Rhizophora stylosa* and *R. mucronata* in the South China Sea. PLOS One, 13(6): 1-18.
56. Wang YH, Xu JC. (2022). Endophytic fungi of agarwood and their chemical compounds. Fungal Biotec 2(2): 16–35.
57. Zhang Z, Yang Y, Wei JH et al. (2010). Advances in studies on mechanism of agarwood formation in *Aquilaria sinensis* and its hypothesis of agarwood formation induced by defence response. Chinese Traditional and Herbal Drugs, 041(001):156-159.
58. Gong LJ, Guo SX. (2009). Endophytic fungi from *Dracaena cambodiana* and *Aquilaria sinensis* and their antimicrobial activity. African Journal of Biotechnology, 8: 731-736.
59. Mohamed R, Jong P, Zali M. (2010). Fungal diversity in wounded stems of *Aquilaria malaccensis*. Fungal Diversity, 43(1), 67-74.
60. Cui JL, Guo SX, Xiao PG. (2011). Antitumor and antimicrobial activities of endophytic fungi from medicinal parts of *Aquilaria sinensis*. J Zhejiang Univ. Sci. B, 12(5): 385-392.
61. Du TY, Karunarathna SC, Zhang X, Dai DQ, Mapook A, Suwannarach N, Tibpromma S. (2022). Endophytic Fungi Associated with *Aquilaria sinensis* (Agarwood) from China Show Antagonism against Bacterial and Fungal Pathogens. Journal of Fungi, 8(11): 1197.

DOI: 10.31579/ 2693-7247/123